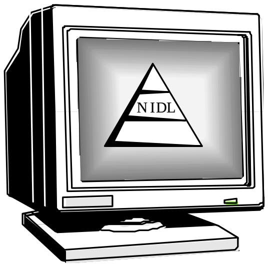

NIMA is looking for a fit, form and function replacement for its aging Tektronix GMA-203 grayscale 19 inch monitor. The 19 inch, 1024 x 1024 pixel addressability, 400 fL maximum luminance GMA-203 stereo monitors have served well and were considered high performance and high quality at the time of initial manufacture. Alternative COTS monitors must have performance comparable to the Tektronix GMA-203. The NIMA team identified the MegaScan MD2-4810-LS grayscale monitor as a potential replacement for the Tektronix monitor. Analysts commented that they were able to see features with the MegaScan that they were not able to see in their well-worn GMA-203 monitors. Based on its tests, NIDL concludes that the MegaScan MD2-4810-LS grayscale monitor (serial number 9007) meets the requirements to serve as a form, fit, and function replacement for the Tektronix GMA-203 as it is presently used as a stereo display in a dark environment.

Evaluation of the MegaScan MD2-4810 LS 11 x 11-Inch Addressable 21-Inch Diagonal Monochrome CRT Monitor

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NIDL IEC Monitor Certification Report

NIDL Evaluation of the MegaScan MD2-4810-LS Grayscale Monitor as a Replacement for the Tektronix GMA-203

FINAL GRADES
Monoscopic Mode: A
Stereoscopic Mode: A

A=Substantially exceeds IEC and/or NIMA Requirements; B= Meets IEC and/or NIMA Requirements; C=Nearly meets IEC and/or NIMA Requirements; F=Fails to meet IEC and/or NIMA Requirements in a substantial way

SUMMARY:
NIDL concludes that the MegaScan MD2-4810-LS grayscale monitor (serial number 9007) meets the requirements to serve as a form, fit, and function replacement for the Tektronix GMA-203 as it is presently used as a stereo display in a dark environment.

BACKGROUND AND TEST RESULTS
NIMA is looking for a fit, form and function replacement for its aging Tektronix GMA-203 grayscale 19 inch monitor. These monitors used in stereo mode with a shutter panel and passive glasses were put into service early in 1991. Now, obtaining service and repair parts for these monitors has become a problem. Increased failure has come about once the GMA-203 monitors are powered down, by power failure, and then restarted. The 19 inch, 1024 x 1024 pixel addressability, 400 fL maximum luminance GMA-203 stereo monitors have served well and were considered high performance and high quality at the time of initial manufacture; NIDL's copy cost over $10,000 in 1990. Alternative COTS monitors must have performance comparable to the Tektronix GMA-203 and must the able to accept the video signal stream from the NIMA system.

The NIMA team identified the MegaScan MD2-4810-LS grayscale monitor as a potential replacement for the Tektronix monitor. In a test at NIMA, the MegaScan MD2-4810-LS monitor passed initial image analyst performance tests. Analysts commented that they were able to see features with the MegaScan that they were not able to see in their well-worn GMA-203 monitors.

To assure that the monitor was set up to the manufacturer's specifications, we requested that a representative, Ronald Hirsch, do any necessary adjustments before we began our tests. The monitor was set for Lmin of 0.27 fL and Lmax of 97 fL per recommendations from the NIMA office. NIDL's tests were performed principally with a signal generator to input video images and test patterns into the MegaScan monitor. We used the IEC Working Group specifications for a grayscale monitor as the basis for our performance tests. In addition, we compared images and test patterns on the MegaScan with NIDL's 10-year-old but little used Tektronix GMA-203, and with a current Siemens SMM21105 LS monitor.

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The details of our measurements are contained within the body of the report. A summary of the salient points is as follows:

- To achieve a good focus, the focus adjustment on the front panel should be used. When the monitor originally came to NIDL, the 3:00 and 9:00 o'clock edges seemed out of focus. Ron Hirsch of MegaScan used the focus adjustment to sharpen the focus at screen center, and thereby at the screen edges. The GMA-203 does not have a similar external adjustment. Thus, it will be important for users of the MegaScan display to adjust the focus, or have program maintenance adjust the focus to assure optimum performance.
- The MegaScan has separate external brightness and contrast controls. These, too, will have to be adjusted for optimum performance. The Tektronix GMA-203 has only an external luminance CONTRAST user control knob and an internal BRIGHTNESS control (O & M adjustable). The MegaScan, like the IEC monitors, was set to operate with a 0.1 fL Lmin for 0-count input. It easily separated the 10% and 5% luminance difference patches throughout the 0 to 100% luminance range. Viewing unclassified images of a ship at dockside with the dock area adjacent to the ship in shadow showed that detail could be seen in the shadow area in the MegaScan monitor. The MegaScan monitor does not have an on-screen display or computer interface. The user control knobs on the front panel of the MegaScan monitor cannot be locked.
- NIDL found that the MegaScan monitor required an unusually long period of time for luminance to settle between changes in input count levels. Delays of up to fives time longer than for other grayscale monitors tested were required when increasing luminance in one-count intervals from 0 to 255 for our tonal transfer curve (TTC) measurements. It is not known whether this unusual behavior has a significant impact on the users' ability to perform their tasks. We also found that the white luminance at the end of the 3-hour measurement had slumped by about 10%, from 97 to 88 fL. We tested the monitor for warm-up using a full white screen over a multi-hour time, but could not repeat the 10% slump. Instead it slumped by less than 3%, in agreement with subsequent tests at MegaScan. This is the tolerance MegaScan intends to hold for the NIMA monitors. MegaScan has re-written their test plan to test NIMA-bound monitors for luminance slump over a multi-hour period.
- MegaScan purchases the CRTs with dispenser cathodes for their monitors from Clinton Electronics. Dispenser cathodes are noteworthy for their longer life compared to scandium-oxide cathodes. To assure good performance of their monitor, MegaScan screens the CRTs for spot size.
- The monitor we had examined had these characteristics. The Clinton A-78 tube had P45 phosphor to reduce ghosting in stereo, and a dispenser cathode instead of the scandium-oxide cathode.
- The beam spot is not perfect at the edges; it shows some flare that distorts its otherwise round shape. However, text and images are still sharp at screen edge perhaps because of a relatively fine electron beam spot. We measured the linewidth on the face of the CRT. At screen center, it measures 6.74 mils Horizontal x 10.7 mils Vertical. The highest horizontal linewidth over the whole screen is 8.25 mils and the highest vertical linewidth is 11.9 mils. The beam is sufficiently fine that the raster shows up very prominently and well resolved. The raster is more prominent at lower than at higher luminance values. The spot may grow with beam current for luminance levels increasing from 10 fL to 76 fL to reduce raster crispness. For comparison, the Siemens monitor has an excellent raster appearance over the range 17 fL to 113 fL.

- The stereo extinction ratio as measured through a StereoGraphics ZScreen and passive glasses averages 29.6:1 for a CRT face luminance of 97 fL resulting in about 12 fL to the photometer/analyst's eyes. We also checked operation closer to the IEC specification of 30 fL after the StereoGraphics optical train. For 190 fL on the CRT, we measured 24 fL to the analyst's eyes with an extinction ratio also of 32.4:1. Operation at the higher luminance level will probably reduce CRT cathode life, so lower luminance levels, e.g., 97 fL, are desirable.
- The reflectivity of the MegaScan monitor face is about 23%, versus about 57% for the Tektronix GMA203 monitor. With the ZScreen in place (instead of the Nuvision LC shutter) as it would be for stereo operation, the reflectivity from the ZScreen was 9% for the MegaScan monitor. It was 12% for the ZScreen (instead of the Nuvision shutter) mounted on the GMA-203 monitor. Thus, the reflectivity of both monitors in stereo operation is about the same.
- NIDL measured good performance in halation, jitter, and contrast modulation so that images look good on the MegaScan.

NIDL concludes that the MegaScan MD2-4810-LS grayscale, single frequency monitor meets the requirements to serve as a form, fit, and function replacement for the Tektronix GMA-203 as it is presently used as a stereo display.

The following timings provided to NIDL are used as GMA-203 default inputs to the VG-819 digital signal generator produced by TEAM Systems:

Pixel Clock / Dot Clock	178.42 MHz
Horizontal Scan Rate / H period	126.72kHz (1408 pixels per line)
Total Line Time (reciprocal of Horizontal Scan Rate)	7.891 µS
Active Image Width / H Disp	11 inches (1024 pixels) 5.739 µS
HDwidth	(1180 pixels)
Horizontal Blanking	2.152 µS (384 pixels)
HSync Front Porch / H Backp	0.5829 µS (104 pixels)
HSync Pulse Width / H Sync	0.8864 µS (176 pixels)
Vertical Field Rate / V Total	60.0Hz (1056 lines total) 8.330 µS
Active Image Height / V Disp	11 inches, 1024 pixels, 8.080 µS
Vertical Field Blanking	252.525 µS (32 lines)
VSync Front Porch	none
VSync Pulse Width / V Sync	55.25 µS (7 lines)
Sync Type	H&V, negative true, TTL levels, 75 Ω
Video Signal	RS-343 RGB, 50 Ω impedance
Peak White	0.714 volts above blank
Peak Black	0.054 volts above blank

The NIMA team established that the square pattern showed up properly as a square on both the Tektronix GMA203 and the MegaScan MD2-4810-LS monitors confirming that the MegaScan is compatible with the GMA203 timing shown above.

The horizontal blanking interval of 2.152 microseconds is difficult to meet with current NIDL-certified grayscale monitors for the IEC program. The minimum horizontal blanking interval for the current Siemens IEC grayscale monitor is about 2.8 microseconds so that this monitor does not correctly display the NIMA input video signal. In about one year, Siemens expects to have revised the circuitry for the 21103/21105 series to accommodate the shorter horizontal-blanking interval required in the NIMA program.

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Evaluation Datasheet

Mode	IEC Requirement	Measured Performance	Compliance
MONOSCOPIC (STEREOSCOPIC format 1024 x 1024 x 120Hz without ZScreen or glasses)			
Addressability	1024 x 1024 min.	1024 x 1024	pass
Dynamic Range	25.4dB	25.6 dB	pass
Luminance (Lmin)	0.1 fL min ± 4%	0.27 fL (d), 0.1 fL (m)	pass
Luminance (Lmax)	35 fL ± 4%	97.4 fL	pass
Uniformity (Lmax)	28% max.	10.7 %	pass
Halation	3.5% max.	2.75± 0.2%	pass
Correlated Color Temp	Not specified	9457 K	
Distance from Daylight Locus	Not specified	0.033 delta u'v'	
Reflectance	Not specified	21.6 %	
Bit Depth	8-bit± 5 counts	8-bit	pass
Step Response	No visible ringing	Clean	pass
Uniformity (Chromaticity)	0.010 ± 0.005 delta u'v' max.	< 0.0024 delta u'v'	pass
Pixel aspect ratio	Square, H = V± 6%	H = V+ 1.2%	pass
Screen size, viewable diagonal	Not specified for stereoscopic	15.495 inches	
Cm, Zone A, 7.6 inch dia.	35% min.	73% H x 83% V	
Cm, Zone A, 40% circle, 7.82 inch diameter	35% min.	73% H x 83% V	pass
Cm, Zone B	20% min.	72% H x 82% V	pass
Pixel density	72 ppi min.	93 ppi	pass
Straightness	0.5% max ± 0.05%	0.27%	pass
Linearity	1.0% max ± 0.5%	0.62 %	pass
Jitter	2 ± 2 mils max.	3.93 mils	pass
Swim, Drift	5 ± 2 mils max.	4.36 / 4.89 mils	pass
Warm-up time, Lmin to +/- 50%	30 ± 0.5 minutes max.	24 min.	pass
Warm-up time, Lmin to +/- 10%	60 ± 0.5 minutes max.	50 mins.	pass
Refresh	72 ±1 Hz min. 60 ±1 Hz absolute minimum	Set to 120 Hz	pass
Briggs Scores for BTP#4 delta-1, -3, -7, -15 contrast	No specification	Delta-1= 21 Delta-3= 51 Delta-7= 71 Delta-15= 81	
STEREOSCOPIC with ZScreen and passive glasses			
Addressability	1024 x 1024 min.	1024 x 1024	pass
Lmin	0.1 fL. Min. ± 4%	0.047 fL (d), 0.093 fL (m)	pass
Lmax	30 fL min ± 4%	12.57 fL (d) 24.69 fL (m)	pass NIMA
Dynamic range	24.77 dB min	24.27 dB (d), 24.24 dB (m)	pass NIMA
Uniformity (Chromaticity)	0.02 delta u'v' max ± 0.005 delta u'v'	0.005 delta'v'	pass
Refresh rate	60 Hz per eye, min	60 Hz per eye	pass
Extinction Ratio	20:1 min	29.6: 1 (d), 32.4: 1 (m)	pass
AMBIENT LIGHTING			
Dynamic Range 22 dB (158:1)	No specification	<1 fc with ZScreen <2 fc for CRT only	
Dynamic Range17.8 dB (60:1)	No specification	<2 fc with ZScreen <7 fc for CRT only	

(d) Denotes monitor CONTRAST and BRIGHTNESS controls set for default values for Lmin = 0.27fL and Lmax = 97fL at the CRT screen..

(m) Denotes monitor CONTRAST and BRIGHTNESS control advanced to maximum setting.

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Section I INTRODUCTION

The National Information Display Laboratory (NIDL) was established in 1990 to bring together technology providers - commercial and academic leaders in advanced display hardware, softcopy information processing tools, and information collaboration and communications techniques - with government users. The Sarnoff Corporation in Princeton, New Jersey, a world research leader in high-definition digital TV, advanced displays, computing and electronics, hosts the NIDL.

The present study evaluates a production unit of the MegaScan MD2-4810 LS monochrome CRT high-resolution display monitor. This report is intended for both technical users, such as system integrators, monitor designers, and monitor evaluators, and non-technical users, such as image analysts, software developers, or other users unfamiliar with detailed monitor technology.

The IEC requirements, procedures and calibrations used in the measurements are detailed in the following:

- *NIDL Publication No. 0201099-091***,** *Request for Evaluation Monitors for the National Imagery & Mapping Agency (NIMA) Integrated Exploitation Capability (IEC),* August 25, 1999.

Two companion documents that describe how the measurements are made are available from the NIDL and the Defense Technology Information Center at http://www.dtic.mil:

- *NIDL Publication No. 171795-036 Display Monitor Measurement Methods under Discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: Monochrome CRT Monitor Performance Draft Version 2.0. (ADA353605)*
- *NIDL Publication No. 171795-037 Display Monitor Measurement Methods under Discussion by EIA (Electronic Industries Association) Committee JT-20 Part 2: Color CRT Monitor Performance Draft Version 2.0. (ADA341357)*

A third document that describes how the measurements are made is available from the NIDL:

- *NIDL Test Procedures for Evaluation of CRT Display Monitors, Version 3.1, 6/15/92*

Other procedures are found in recently approved standards available from the Video Electronics Standards Association (VESA) at http://www.vesa.org:

- *VESA Flat Panel Display Measurements Standard, Version 1.0, May 15, 1998.*
- *VESA Flat Panel Display Measurements Standard, Version 2.0, June 2001.*

The IEC workstation provides the capability to display image and other geospatial data on either monochrome or color monitors, or a combination of both. Either of these monitors may be required to support stereoscopic viewing. Selection and configuration of these monitors will be made in accordance with mission needs for each site. NIMA users will select from monitors included on the NIMA-approved Certified Monitor List compiled by the NIDL. The color and monochrome, monoscopic and stereoscopic, monitor requirements are listed in the Evaluation Datasheet.

I.1 The MegaScan MD2-4810 LS Monochrome CRT Monitor

Please see manufacturer's quoted features for the MD2-4810 LS at http://www.megascandisplays.com/html_pages/products.html . As of January 2003, for product support please contact Pat Waltz at:

Z-Axis
1916 Route 96
Phelps, NY 14532
Tel. (315) 548-5000
Fax (315) 548-5100

MegaScan Specifications

As of January 2003, please contact Z-Axis at 315-548-5000 for the 12 page detailed product specifications for the MegaScan MD2-4810 LS monitor.

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I.2. Initial Monitor Set Up

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5, p 5.

To assure that the monitor was set up to the manufacturer's specifications, we requested that a representative, Ronald Hirsch, do any necessary adjustments before we began our tests. The monitor was set for Lmin of 0.27 fL and Lmax of 97 fL per recommendations from the NIMA office.

All measurements will be made with the display commanded through a laboratory grade programmable test pattern generator. The system will be operated in at least a 24 bit mode (as opposed to a lesser or pseudo-color mode) for color and at least 8 bits for monochrome. As a first step, refresh rate should be measured and verified to be at least 72 Hz. The screen should then be commanded to full addressability and Lmin set to 0.1 fL. Lmax should be measured at screen center with color temperature between D65 and D93 allowable and any operator adjustment of gain allowable. If a value >35fL is not achieved (>30 fL for color), addressability should be lowered. For a nominal 1200 by 1600 addressability, addressability should be lowered to 1280 by 1024 or to 1024 by 1024. For a nominal 2048 by 2560 addressability, addressabilities of 1200 x 1600 and 1024 x 1024 can be evaluated if the desired Lmax is not achieved at full addressability.

I.3. Equipment

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0 Section 2.0, page 3.

The procedures described in this report should be carried out in a darkened environment such that the stray luminance diffusely reflected by the screen in the absence of electron-beam excitation is less than 0.003 cd/m^2 (1mfL).

Instruments used in these measurements included:

- Quantum Data 8701 400 MHz programmable test pattern signal generator
- Photo Research SpectraScan PR-650 spectroradiometer
- Photo Research SpectraScan PR-704 spectroradiometer
- Minolta LS-100 Photometer
- Minolta CA-100 Colorimeter
- Graseby S370 Illuminance Meter
- Microvision Superspot 100 Display Characterization System which included:
  - OM-1 optic module (Two Dimensional photodiode linear array device, projected element size at screen set to 1.3 mils with photopic filter),
  - OM-5 optic module (Two Dimensional CCD linear array device, projected element size at screen set to 0.21 mils with photopic filter), and
  - Spotseeker 4-Axis Positioner.

Stereoscopic-mode measurements were made using the following commercially-available stereo products:

- StereoGraphics passive polarized glasses and ZScreen active 19-inch LC shutter panel

Section II PHOTOMETRIC MEASUREMENTS

II.1. Dynamic range and Screen Reflectance

References: *Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.6, p 6.*

VESA Flat Panel Display Measurements Standard, Version 1.0, May 15, 199, Section 308-1.

Full screen white-to-black dynamic range measured in 1024 x 1024 format is 25.6 dB in a dark room with Lmax set to 97 fL and Lmin set to 0.27 fL. Viewed through the ZScreen and passive polarized glasses, the dynamic range in a dark room decreases to 24.3dB. It decreases to under 22 dB (the absolute threshold for IEC) in 1 fc diffuse ambient illumination incident on the screen.

Objective: Measure the photometric output (luminance vs. input command level) at Lmax and Lmin in both dark room and illuminated ambient conditions.

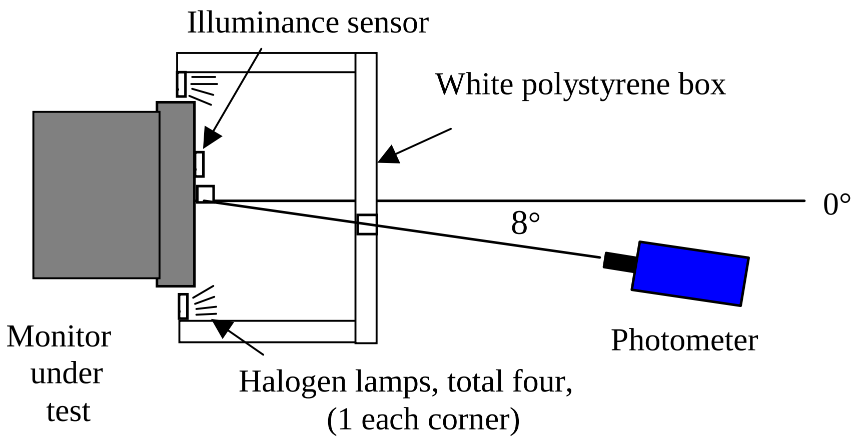
Equipment: Photometer, Integrating Hemisphere Light Source or equivalent

Procedure: Luminance at center of screen is measured for input counts of 0 and Max Count. Test targets are full screen (flat fields) where full screen is defined addressability. Set Lmin to 0.1 fL. For color monitors, set color temperature between D_{65} to D_{93}. Measure Lmax.

This procedure applies when intended ambient light level measured at the display is 2fc or less. For conditions of higher ambient light level, Lmin and Lmax should be measured at some nominal intended ambient light level (e.g., 18-20 fc for normal office lighting with no shielding). This requires use of a remote spot photometer following procedures outlined in reference 2, paragraph 308-2. This will at best be only an approximation since specular reflections will not be captured. A Lmin > 0.1 fL may be required to meet grayscale visibility requirements.

According to the VESA directed hemispherical reflectance (DHR) measurement method, total combined reflections due to specular, haze and diffuse components of reflection arising from uniform diffuse illumination are simultaneously quantified as a fraction of the reflectance of a perfect white diffuse reflector using the set up depicted in figure II.1-1. Total reflectance was calculated from measured luminances reflected by the screen (display turned off) when uniformly illuminated by an integrating hemisphere simulated using a polystyrene icebox. Luminance is measured using a spot photometer with 1° measurement field and an illuminance sensor as depicted in Figure II.1-1. The measured values and calculated reflectances are given in Table II.1-1.

Data: Define dynamic range by: $DR=10\log(Lmax/Lmin)$



- Top View -

Figure II.1-1. Test setup according to VESA FPDM procedures for measuring total reflectance of screen.

Table II.1-1. Directed Hemispherical Reflectance of Faceplate

VESA ambient contrast illuminance source (polystyrene box)

	CRT Only	With ZScreen
Ambient Illuminance	20.26 fc	20.45 fc
Reflected Luminance	4.38 fL	1.83 fL
Faceplate Reflectance	21.6 %	9.0 %

Ambient dynamic ranges of full screen white-to-black given in Table II.1-2 were computed for various levels of diffuse ambient lighting using the measured value for DHR and the darkroom dynamic range measurements. When viewed through the stereoscopic ZScreen and passive polarized glasses, full screen white-to-black dynamic range decreases from 24.3 dB in a dark room to less than 22 dB (the absolute threshold for IEC) in 1 fc diffuse ambient illumination.

Table II.1-2.Dynamic Range in Dark and Illuminated Rooms

Effect of ambient lighting on dynamic range is calculated by multiplying the measured CRT faceplate reflectivity times the ambient illumination measured at the CRT in foot candles added to the minimum screen luminance, Lmin.

Ambient Illumination	**Dynamic Range**	
	As viewed at the CRT No ZScreen or glasses *Lmin = 0.27fL, Lmax = 97.0 fL*	**As viewed through ZScreen and passive polarized glasses** *Lmin = 0.047fL, Lmax = 12.57 fL*
0 fc (Dark Room)	25.6 dB	24.3 dB
1 fc	23.0 dB	19.7 dB
2 fc	21.4 dB	17.5 dB
3 fc	20.3 dB	16.1 dB
4 fc	19.4 dB	15.0 dB
5 fc	18.6 dB	14.2 dB
6 fc	18.0 dB	13.5 dB
7 fc	17.4 dB	12.9 dB
8 fc	16.9 dB	12.4 dB
9 fc	16.5 dB	12.0 dB
10 fc	16.1 dB	11.6 dB

II.2. Maximum Luminance (Lmax)

References: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.2, p 6.

The highest luminance for Lmax was 97.4fL measured at screen center in 1024 x 1024 format.

Objective: Measure the maximum output display luminance.

Equipment: Photometer

Procedure: See dynamic range. Use the value of Lmax defined for the Dynamic Range measurement.

Data: The maximum output display luminance, Lmax, and associated CIE x, y chromaticity coordinates (CIE 1976) were measured using a hand-held colorimeter (Minolta CA-100). The correlated color temperature (CCT) computed from the measured CIE x, y chromaticity coordinates was within range specified by IEC (6500K and 9300K).

Table II.2-1. Maximum Luminance and Color

Color and luminance (in fL) for Full screen at 100% Lmax taken at screen center.

Format	CCT	CIE x	CIE y	Luminance
1024 x 1024	9457 K	0.263	0.336	97.4 fL

II.3. Luminance (Lmax) and Color Uniformity

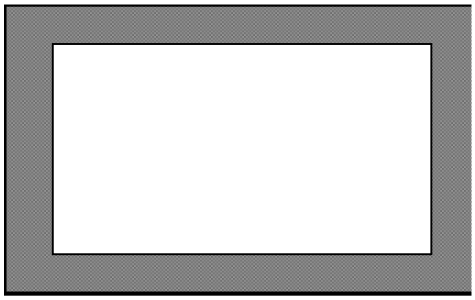
Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 4.4, p. 28.

Maximum luminance (Lmax) varied by up to 10.7 % across the screen. Chromaticity variations were less than 0.0024 delta u'v' units.

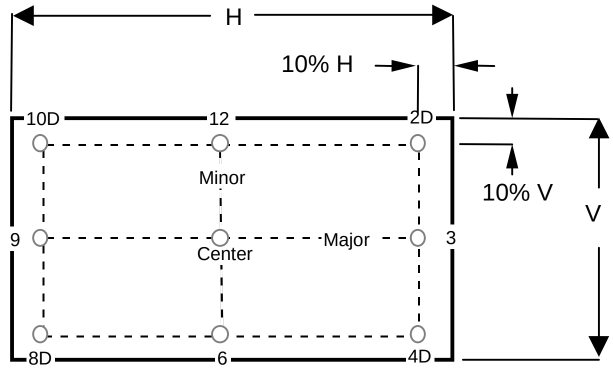
Objective: Measure the variability of luminance and chromaticity coordinates of the white point at 100% Lmax only and as a function of spatial position. Variability of luminance impacts the total number of discriminable gray steps.

Equipment:
- Video generator
- Photometer
- Spectroradiometer or Colorimeter

Test Pattern: Full screen flat field with visible edges at L_{min} as shown in Figure II.3-1.



Full Screen Flat Field test pattern.
Figure II.3-1



Nine screen test locations.
Figure II.3-2

Procedure: Investigate the temporal variation of luminance and the white point as a function of intensity by displaying a full flat field shown in Figure II.3-1 for video input count levels corresponding L_{max}. Measure the luminance and C.I.E. color coordinates at center screen.

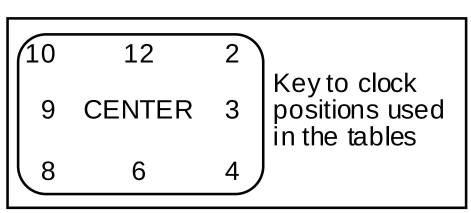
Investigate the temporal variation of luminance and the white point as a function of spatial position by repeating these measurements at each of the locations depicted in Figure II.3-2. Define color uniformity in terms of delta u´v´.

Data: Tabulate the luminance and 1931 C.I.E. chromaticity coordinates (x, y) or correlated color temperature of the white point at each of the nine locations depicted in Figure II.3-2. Additionally, note the location of any additional points that are measured along with the corresponding luminance values.

Table II.3-1.Spatial Uniformity of Luminance and Color
Color and luminance (in fL) for Full screen at 100% Lmax taken at nine screen positions.

1024 x 1024

POSITION	CCT	CIE x	CIE y	L, fL
center	9457	0.263	0.336	97.4
2	9699	0.261	0.333	88.4
3	9664	0.261	0.334	90.6
4	9771	0.260	0.333	89.5
6	9664	0.261	0.334	93.4
8	9771	0.260	0.333	96.7
9	9664	0.261	0.334	99.0
10	9734	0.261	0.332	95.6
12	9664	0.261	0.334	92.0



1024 x 1024

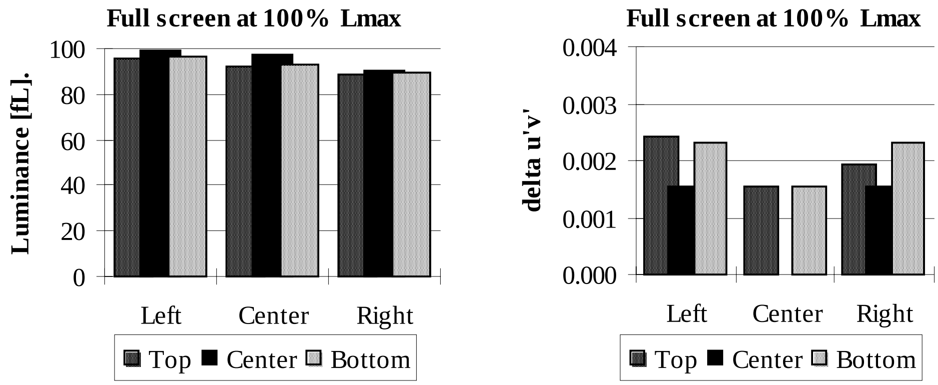


Fig.II.3-3. Spatial Uniformity of Luminance and Chromaticity.
(Delta u'v' of 0.004 is just visible.)

II.4. Halation

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0 Section 4.6, page 48.

Halation was 2.75% ±0.2% on a small black patch surrounded by a large full white area.

Objective: Measure the contribution of halation to contrast degradation. Halation is a phenomenon in which the luminance of a given region of the screen is increased by contributions from surrounding areas caused by light scattering within the phosphor layer and internal reflections inside the glass faceplate. The mechanisms that give rise to halation, and its detailed non-monotonic dependence on the distance along the screen between the source of illumination and the region being measured have been described by E. B. Gindele and S.L. Shaffer. The measurements specified below determine the percentage of light that is piped into the dark areas as a function of the extent of the surrounding light areas.

Equipment:
- Photometer
- Video generator

Test Pattern:

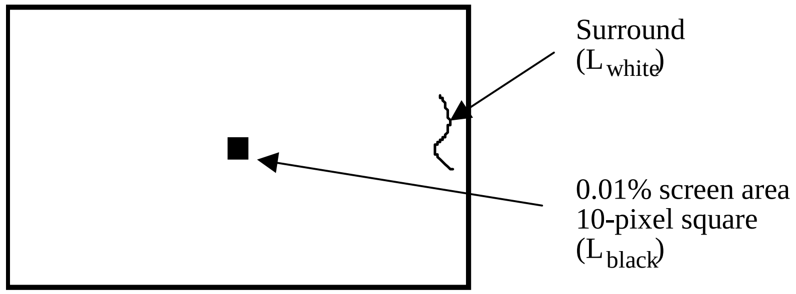


Figure II.4-1 *Test pattern for measuring halation.*

Procedure: Note: The halation measurements require changing the setting of the BRIGHTNESS control and will perturb the values of L_{max} and L_{min} that are established during the initial monitor set-up. The halation measurements should therefore be made either first, before the monitor setup, or last, after all other photometric measurements have been completed.

Determine halation by measuring the luminance of a small square displayed at L_{black} (essentially zero) and at L_{white} when surrounded by a much larger square displayed at L_{white} (approximately 75% L_{max}).

Establish L_{black} by setting the display to cutoff. To set the display to cut-off, display a flat field using video input count level zero, and use a photometer to monitor the luminance at center screen. Vary the BRIGHTNESS control until the CRT beam is visually cut off, and confirm that the corresponding luminance (L_{stray}) is essentially equal to zero. Fine tune the BRIGHTNESS control such that CRT beam is just on the verge of being cut off. These measurements should be made with a photometer, which is sensitive at low light levels (below L_{min} of the display). Make no further adjustments or changes to the BRIGHTNESS control or the photometer measurement field.

Next, decrease the video input level to display a measured full-screen luminance of 75% L_{max} measured at screen center. Record this luminance (L_{white}).

The test target used in the halation measurements is a black (L_{black}) square patch of width equal to 0.01% of the area of addressable screen, the interior square as shown in Figure II.4-1. The interior square patch is enclosed in a white (L_{white}) background encompassing the remaining area of the image. The exterior surround will be displayed at 75% L_{max} using the input count level for L_{white} as determined above. The interior square will be displayed at input digital count level zero.

Care must be taken during the luminance measurement to ensure that the photometer's measurement field is less than one-half the size of the interior square and is accurately positioned not to extend beyond the boundary of the interior square. The photometer should be checked for light scattering or lens flare effects which allow light from the surround to enter the photosensor. A black card with aperture equal to the measurement field (one-half the size of the interior black

square) may be used to shield the photometer from the white exterior square while making measurements in the interior black square.

Analysis: Compute the percent halation for each test target configuration. Percent halation is defined as:

$$\% \text{ Halation} = L_{black} \, / \, (L_{white} - L_{black}) \times 100$$

Where, L_{black} = measured luminance of interior square displayed at L_{black} using input count level zero,

L_{white} = measured luminance of interior square displayed at L_{white} using input count level determined to produce a full screen luminance of 75% L_{max} .

Data: Table II.4-1 contains measured values of L_{black}, L_{white} and percentage halation.

Table II.4-1 Halation for 1024 x 1024 Addressability

	Reported Values	Range for 4% uncertainty
Lblack	1.10 fL ± 4%	1.05 fL to 1.14 fL
Lwhite	39.9 fL ± 4%	38.3 fL 41.5 fL
Halation	2.75% ± 0.2%	2.54% to 2.98%

II.5. Color Temperature

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0 Section 5.4, page 22.

The CCT of the measured white point is 9457K and lies 0.033 delta u'v' units from the CIE Daylight Locus. CCT is not specified for monochrome monitors for IEC.

Objective: Insure measured screen white of a color monitor has a correlated color temperature (CCT) between 6500K and 9300K.

Equipment: Colorimeter

Procedure: Command screen to Lmax. Measure u’v’ chromaticity coordinates (CIE 1976).

Data: Coordinates of screen white should be within 0.01 Δu’v’ of the corresponding CIE daylight, which is defined as follows: If the measured screen white has a CCT between 6500 and 9300 K, the corresponding daylight has the same CCT as the screen white. If the measured CCT is greater than 9300 K, the corresponding daylight is D93. If the measured CCT is less than 6500 K, the corresponding daylight is D65. The following equations were used to compute Δu’v’ values listed in table II.5.1:

1. Compute the correlated color temperature (CCT) associated with (x,y) by the VESA/McCamy formula: CCT = 437 n^3 + 3601 n^2 + 6831 n + 5517, where n = (x-0.3320)/(0.1858 - y). [This is on p. 227 of the FPDM standard]

2. If CCT < 6500, replace CCT by 6500. If CCT > 9300, replace CCT by 9300.

4. Use formulas 5(3.3.4) and 6(3.3.4) in Wyszecki and Stiles (pp.145-146 second edition) to compute the point (xd,yd) associated with CCT.
   - First, define u = 1000/CCT.
   - If CCT < 7000, then xd = -4.6070 u^3 + 2.9678 u^2 + 0.09911 u +
   - 0.244063.
   - If CCT > 7000, then xd = -2.0064 u^3 + 1.9018 u^2 + 0.24748 u +
   - 0.237040.
   - In either case, yd = -3.000 xd^2 + 2.870 xd -0.275.

5. Convert (x,y) and (xd,yd) to u'v' coordinates:
   - (u',v') = (4x,9y)/(3 + 12y - 2x)
   - (u'd,v'd) = (4xd,9yd)/(3 + 12yd - 2xd)

6. Evaluate delta-u'v' between (u',v') and (ud,vd):
   - delta-u'v' = sqrt[(u' - u'd)^2 + (v' - v'd)^2].

7. If delta-u'v' is greater than 0.01, display fails the test. Otherwise it passes the test.

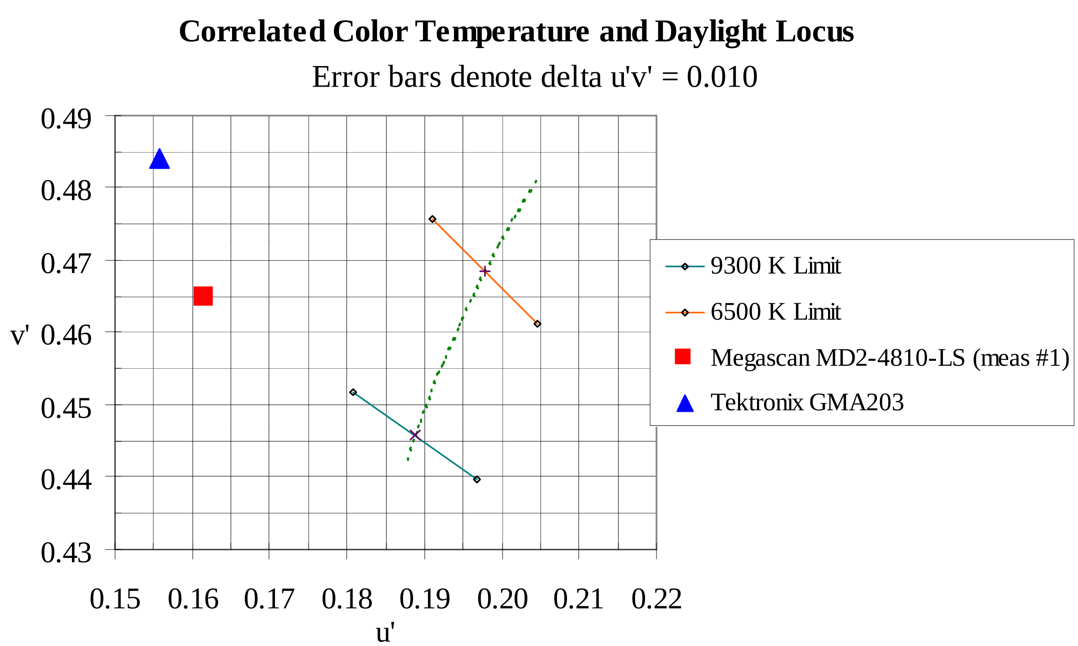


Figure II.5-1 *CCT of measured white points relative to the Daylight Locus.*

Table II.5-1 Δu'v' Distances between measured white point and CIE coordinate values from D_{65} to D_{93}.

	Megascan MD2-4810-LS	**Tektronix GMA203**
CIE x	0.263	0.270
CIE y	0.336	0.373
CIE u'	0.162	0.156
CIE v'	0.465	0.484
CCT	9457	8190
delta u'v'	**0.033**	**0.047**

II.6. Bit Depth

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.6, p 6.

Monotonic increases in luminance were measured for each of the 256 input levels for 8 bits of gray scale. Neither black level clipping nor white level saturation was observed.

Objective: Measure the number of bits of data that can be displayed as a function of the DAC and display software.

Equipment: Photometer

Test targets: Targets are four inch patches with command levels of all commandable levels; e.g., 256 for 8 bit display. Background is commanded to 0.5* ((0.7 *P)+0.3*n) where P = patch command level, n = number of command levels.

Procedure: Measure patch center for all patches with Lmin and Lmax as defined previously. Count number of monotonically increasing luminance levels. Use the NEMA/DICOM to define discriminable luminance differences. For color displays, measure white values.

Data: Define bit depth by $\log_2$ (number of discrete luminance levels)

The number of bits of data that can be displayed as a function of the input signal voltage level were verified through measurements of the luminance of white test targets displayed using a Quantum Data 8701 test pattern generator and a Minolta CA-100 colorimeter. Targets are n four-inch patches with command levels of all commandable levels; e.g., 256 for 8 bit display. Background is commanded to 0.5* ((0.7 *P)+0.3*n) where P = patch command level, n = number of command levels. The NEMA/DICOM was used to define discriminable luminance differences in JNDs.

Figure II.6-1 shows the System Tonal Transfer curve at center screen as a function of input counts. Figure II.6-2 shows the perceptible differences between gray levels according to the NEMA/DICOM JND metric. The data for each of the 256 levels are listed in Tables II.6-1 and II.6-2.

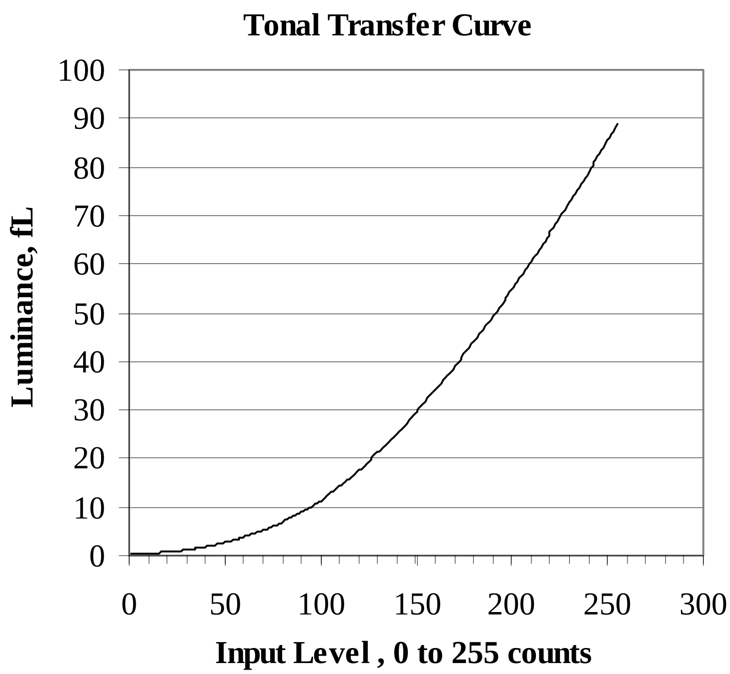


Figure II.6-1. System Tonal Transfer at center screen as a function of input counts.

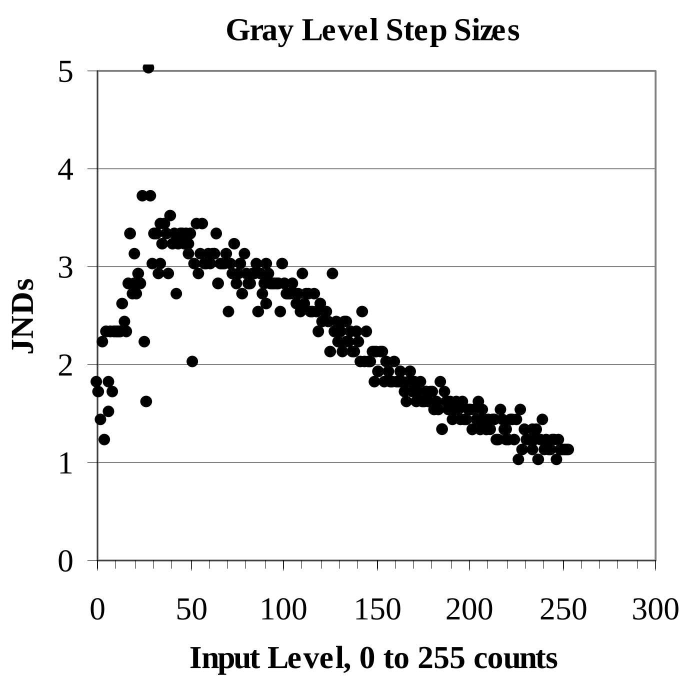


Figure II.6-2. Perceptibility of gray level steps at center screen as a function of input counts.

Table II.6-1. System Tonal Transfer at center screen as a function of input counts 000 to 127.

Background	Target	L, fL	Diff, fL	Diff, JND	Background	Target	L, fL	Diff, fL	Diff, JND
38	0	0.304	0	0.0	61	64	4.323	0.135	3.1
39	1	0.317	0.013	1.8	61	65	4.46	0.137	3.1
39	2	0.33	0.013	1.7	62	66	4.612	0.152	3.3
39	3	0.341	0.011	1.4	62	67	4.746	0.134	2.8
40	4	0.358	0.017	2.2	62	68	4.892	0.146	3.0
40	5	0.368	0.01	1.2	63	69	5.041	0.149	3.0
41	6	0.387	0.019	2.3	63	70	5.192	0.151	3.0
41	7	0.403	0.016	1.8	63	71	5.35	0.158	3.1
41	8	0.416	0.013	1.5	64	72	5.487	0.137	2.5
42	9	0.436	0.02	2.3	64	73	5.648	0.161	3.0
42	10	0.452	0.016	1.7	64	74	5.808	0.16	2.9
42	11	0.474	0.022	2.3	65	75	5.986	0.178	3.2
43	12	0.496	0.022	2.3	65	76	6.15	0.164	2.8
43	13	0.519	0.023	2.3	65	77	6.322	0.172	2.9
43	14	0.543	0.024	2.3	66	78	6.506	0.184	3.0
44	15	0.571	0.028	2.6	66	79	6.687	0.181	3.0
44	16	0.597	0.026	2.4	66	80	6.859	0.172	2.7
44	17	0.623	0.026	2.3	67	81	7.06	0.201	3.1
45	18	0.656	0.033	2.8	67	82	7.25	0.19	2.9
45	19	0.696	0.04	3.3	67	83	7.437	0.187	2.8
45	20	0.729	0.033	2.7	68	84	7.632	0.195	2.8
46	21	0.769	0.04	3.1	68	85	7.834	0.202	2.9
46	22	0.807	0.038	2.8	69	86	8.041	0.207	2.9
46	23	0.844	0.037	2.7	69	87	8.266	0.225	3.0
47	24	0.885	0.041	2.9	69	88	8.45	0.184	2.5
47	25	0.925	0.04	2.8	70	89	8.674	0.224	2.9
48	26	0.982	0.057	3.7	70	90	8.884	0.21	2.7
48	27	1.016	0.034	2.2	70	91	9.106	0.222	2.8
48	28	1.041	0.025	1.6	71	92	9.343	0.237	3.0
49	29	1.123	0.082	5.0	71	93	9.564	0.221	2.6
49	30	1.187	0.064	3.7	71	94	9.81	0.246	2.9
49	31	1.241	0.054	3.0	72	95	10.05	0.24	2.8
50	32	1.301	0.06	3.3	72	96	10.29	0.24	2.8
50	33	1.364	0.063	3.3	72	97	10.54	0.25	2.8
50	34	1.421	0.057	2.9	73	98	10.8	0.26	2.8
51	35	1.489	0.068	3.4	73	99	11.06	0.26	2.8
51	36	1.552	0.063	3.0	73	100	11.3	0.24	2.5
51	37	1.62	0.068	3.2	74	101	11.59	0.29	3.0
52	38	1.695	0.075	3.4	74	102	11.87	0.28	2.8
52	39	1.769	0.074	3.3	74	103	12.14	0.27	2.7
52	40	1.838	0.069	2.9	75	104	12.42	0.28	2.7
53	41	1.923	0.085	3.5	75	105	12.7	0.28	2.7
53	42	2.002	0.079	3.2	76	106	13	0.3	2.8
53	43	2.085	0.083	3.3	76	107	13.29	0.29	2.7
54	44	2.156	0.071	2.7	76	108	13.59	0.3	2.7
54	45	2.242	0.086	3.2	77	109	13.89	0.3	2.6
55	46	2.336	0.094	3.3	77	110	14.2	0.31	2.7
55	47	2.429	0.093	3.3	77	111	14.49	0.29	2.5
55	48	2.523	0.094	3.2	78	112	14.83	0.34	2.9
56	49	2.622	0.099	3.3	78	113	15.15	0.32	2.6
56	50	2.723	0.101	3.2	78	114	15.48	0.33	2.7
56	51	2.822	0.099	3.1	79	115	15.82	0.34	2.7
57	52	2.927	0.105	3.3	79	116	16.15	0.33	2.5
57	53	2.997	0.07	2.0	79	117	16.48	0.33	2.5
57	54	3.097	0.1	3.0	80	118	16.83	0.35	2.7
58	55	3.219	0.122	3.4	80	119	17.17	0.34	2.5
58	56	3.321	0.102	2.9	80	120	17.49	0.32	2.3
58	57	3.435	0.114	3.1	81	121	17.86	0.37	2.6
59	58	3.564	0.129	3.4	81	122	18.22	0.36	2.6
59	59	3.683	0.119	3.0	81	123	18.57	0.35	2.4
59	60	3.8	0.117	3.0	82	124	18.94	0.37	2.5
60	61	3.928	0.128	3.1	82	125	19.31	0.37	2.5
60	62	4.054	0.126	3.0	83	126	19.69	0.38	2.4
60	63	4.188	0.134	3.1	83	127	20.01	0.32	2.1

Table II.6-2. System Tonal Transfer at center screen as a function of input counts 128 to 255.

Background	Target	L, fL	Diff, fL	Diff, JND
83	128	20.47	0.46	2.9
84	129	20.83	0.36	2.3
84	130	21.23	0.4	2.4
84	131	21.59	0.36	2.2
85	132	21.97	0.38	2.3
85	133	22.34	0.37	2.1
85	134	22.75	0.41	2.4
86	135	23.18	0.43	2.4
86	136	23.56	0.38	2.2
86	137	23.96	0.4	2.2
87	138	24.39	0.43	2.3
87	139	24.79	0.4	2.1
87	140	25.19	0.4	2.1
88	141	25.62	0.43	2.3
88	142	26.05	0.43	2.2
88	143	26.46	0.41	2.0
89	144	26.95	0.49	2.5
89	145	27.36	0.41	2.0
90	146	27.84	0.48	2.3
90	147	28.26	0.42	2.0
90	148	28.68	0.42	2.0
91	149	29.13	0.45	2.1
91	150	29.6	0.47	2.1
91	151	30	0.4	1.8
92	152	30.47	0.47	2.1
92	153	30.91	0.44	1.9
92	154	31.38	0.47	2.1
93	155	31.87	0.49	2.1
93	156	32.31	0.44	1.8
93	157	32.78	0.47	2.0
94	158	33.24	0.46	1.9
94	159	33.68	0.44	1.8
94	160	34.15	0.47	1.8
95	161	34.64	0.49	2.0
95	162	35.11	0.47	1.8
95	163	35.58	0.47	1.8
96	164	36.05	0.47	1.8
96	165	36.54	0.49	1.9
97	166	37.04	0.5	1.8
97	167	37.5	0.46	1.7
97	168	37.94	0.44	1.6
98	169	38.44	0.5	1.8
98	170	38.96	0.52	1.9
98	171	39.43	0.47	1.7
99	172	39.96	0.53	1.8
99	173	40.42	0.46	1.6
99	174	40.92	0.5	1.7
100	175	41.47	0.55	1.8
100	176	41.94	0.47	1.6
100	177	42.44	0.5	1.6
101	178	42.96	0.52	1.7
101	179	43.49	0.53	1.7
101	180	43.98	0.49	1.6
102	181	44.51	0.53	1.7
102	182	45.06	0.55	1.7
102	183	45.56	0.5	1.5
103	184	46.09	0.53	1.6
103	185	46.58	0.49	1.5
104	186	47.17	0.59	1.8
104	187	47.63	0.46	1.3
104	188	48.19	0.56	1.7
105	189	48.74	0.55	1.6
105	190	49.27	0.53	1.5
105	191	49.82	0.55	1.6

Background	Target	L, fL	Diff, fL	Diff, JND
106	192	50.38	0.56	1.5
106	193	50.87	0.49	1.4
106	194	51.43	0.56	1.5
107	195	52.01	0.58	1.6
107	196	52.54	0.53	1.5
107	197	53.06	0.52	1.4
108	198	53.67	0.61	1.6
108	199	54.23	0.56	1.4
108	200	54.75	0.52	1.4
109	201	55.34	0.59	1.5
109	202	55.92	0.58	1.5
109	203	56.45	0.53	1.3
110	204	57.03	0.58	1.5
110	205	57.59	0.56	1.4
111	206	58.23	0.64	1.6
111	207	58.81	0.58	1.4
111	208	59.36	0.55	1.3
112	209	59.98	0.62	1.5
112	210	60.56	0.58	1.4
112	211	61.12	0.56	1.3
113	212	61.73	0.61	1.4
113	213	62.31	0.58	1.3
113	214	62.9	0.59	1.4
114	215	63.51	0.61	1.4
114	216	64.07	0.56	1.2
114	217	64.62	0.55	1.2
115	218	65.29	0.67	1.5
115	219	65.91	0.62	1.4
115	220	66.52	0.61	1.3
116	221	67.09	0.57	1.2
116	222	67.67	0.58	1.3
116	223	68.24	0.57	1.2
117	224	68.91	0.67	1.4
117	225	69.58	0.67	1.4
118	226	70.19	0.61	1.2
118	227	70.83	0.64	1.4
118	228	71.36	0.53	1.0
119	229	72.09	0.73	1.5
119	230	72.65	0.56	1.1
119	231	73.29	0.64	1.3
120	232	73.9	0.61	1.2
120	233	74.51	0.61	1.2
120	234	75.13	0.62	1.2
121	235	75.8	0.67	1.3
121	236	76.38	0.58	1.1
121	237	77.05	0.67	1.2
122	238	77.72	0.67	1.3
122	239	78.28	0.56	1.0
122	240	78.92	0.64	1.2
123	241	79.65	0.73	1.4
123	242	80.29	0.64	1.1
123	243	80.95	0.66	1.2
124	244	81.55	0.6	1.1
124	245	82.16	0.61	1.1
125	246	82.86	0.7	1.2
125	247	83.53	0.67	1.2
125	248	84.12	0.59	1.0
126	249	84.82	0.7	1.2
126	250	85.46	0.64	1.1
126	251	86.07	0.61	1.1
127	252	86.74	0.67	1.1
127	253	87.41	0.67	1.1
127	254	88.06	0.65	1.1
128	255	88.7	0.64	1.1

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II.8. Luminance Step Response

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.8, p 7.

No video artifacts were observed.

Objective: Determine the presence of artifacts caused by undershoot or overshoot.

Equipment: Test targets, SMPTE Test Pattern RP-133-1991, 2-D CCD array

Procedure: Display a center box 15% of screen size at input count levels corresponding to 25%, 50%, 75%, and 100% of Lmax with a surround of count level 0. Repeat using SMPTE Test pattern

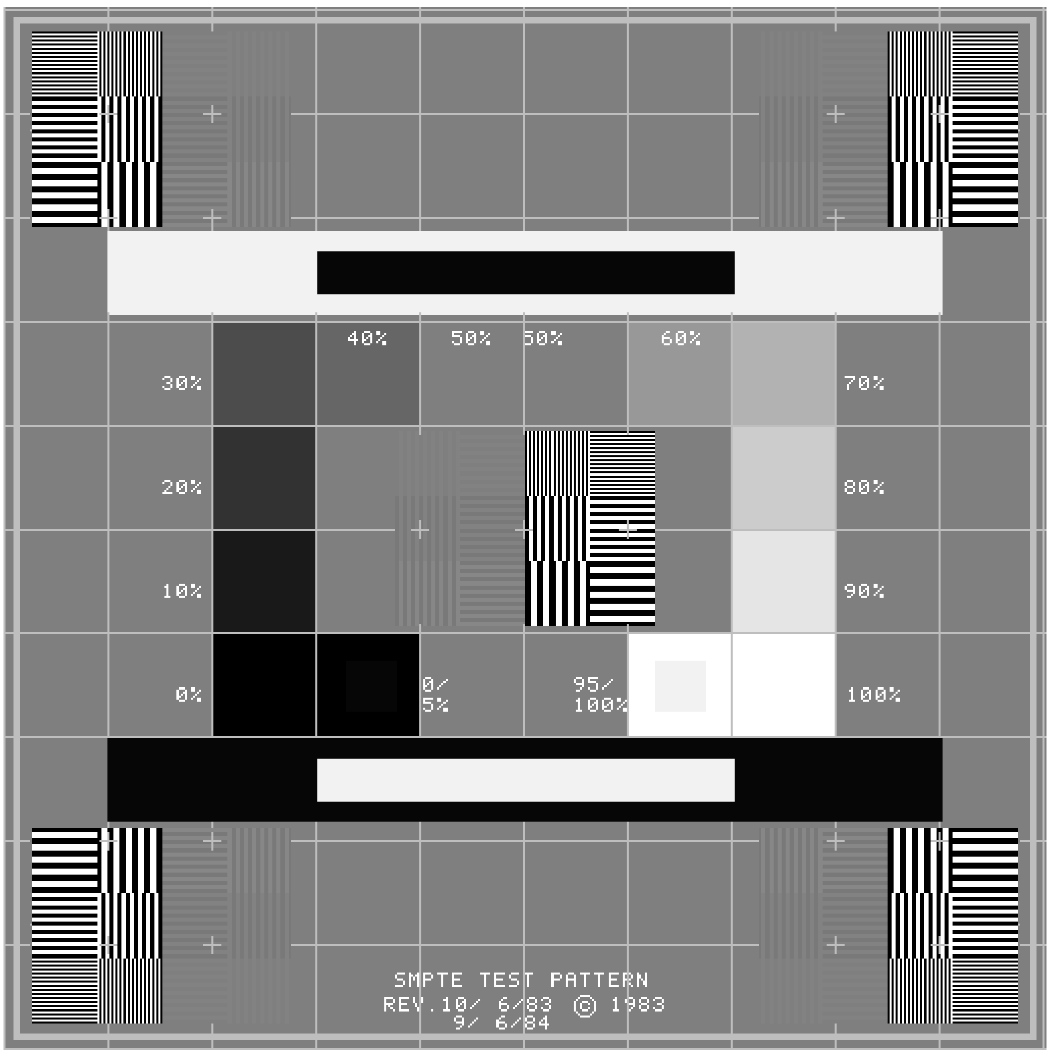

Figure II.8-1. SMPTE Test Pattern.

Data: Define pass by absence of noticeable ringing, undershoot, overshoot, or streaking.

The test pattern shown in Figure II.8-1 was used in the visual evaluation of the monitor. This test pattern is defined in SMPTE Recommended Practice RP-133-1986 published by the Society of Motion Picture and Television Engineers (SMPTE) for medical imaging applications. Referring to the large white-in-black and black-in-white horizontal bars contained in the test pattern, RP133-1986, paragraph 2.7 states " These areas of maximum contrast facilitate detection of mid-band streaking (poor low-frequency response), video amplifier ringing or overshoot, deflection interference, and halo." None of these artifacts was observed in the MegaScan monitor, signifying good electrical performance of the video circuits.

II.9. Addressability

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 6.1, page 67.

This monitor properly displayed all addressed pixels for the following tested format (HxV): 1024 x 1024 x 120 Hz.

Objective: Define the number of addressable pixels in the horizontal and vertical dimension; confirm that stated number of pixels is displayed.

Equipment: Programmable video signal generator.
Test pattern with pixels lit on first and last addressable rows and columns and on two diagonal lines beginning at upper left and lower right; H & V grill patterns 1-on/1-off.

Procedure: The number of addressed pixels were programmed into the Quantum Data 8701 test pattern generator for 73 Hz minimum for monoscopic mode and 120 Hz minimum for stereoscopic mode, where possible. All perimeter lines were confirmed to be visible, with no irregular jaggies on diagonals and, for monochrome monitors, no strongly visible moiré on grilles.

Data: If tests passed, number of pixels in horizontal and vertical dimension. If test fails, addressability unknown.

Table II.9-1 Addressabilities Tested

Stereo Mode
1024 x 1024 x 120 Hz

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II.10. Pixel Aspect Ratio

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.10, p 8.

Pixel aspect ratio is 1:1.

Objective: Characterize aspect ratio of pixels.

Equipment: Test target, measuring tape with at least 1/16th inch increments

Procedure: Display box of 400 x 400 pixels at input count corresponding to 50% Lmax and background of 0. Measure horizontal and vertical dimension.

Alternatively, divide number of addressable pixels by the total image size to obtain nominal pixel spacings in horizontal and vertical directions.

Data: Define pass if H= V± 6% for pixel density <100 ppi and ± 10% for pixel density > 100 ppi.

	Stereoscopic Mode	
	400 x 400 Pixel Box	1024 x 1024 Full Screen
H x V Image Size (inches)	4.308 x 4.257	10.996 x 10.918
H x V Pixel Spacing (mils)	10.77 x 10.64	10.74 x 10.66
H x V Pixel Aspect Ratio	H = V + 1.2%	H = V + 0.75%

II.11. Screen Size (Viewable Active Image)

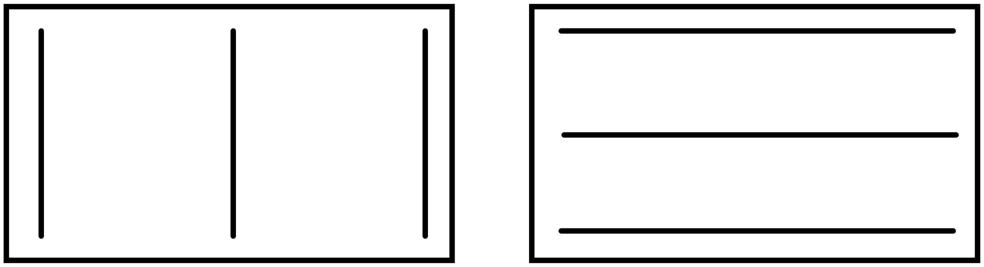
Reference: VESA Flat Panel Display Measurements Standard, Version 1.0, May 15, 1998, Section 501-1.

Image size as tested (1024 x 1024) was 15.495 inches in diagonal.

Objective: Measure beam position on the CRT display to quantify width and height of active image size visible by the user (excludes any overscanned portion of an image).

Equipment:
- Video generator
- Spatially calibrated CCD or photodiode array optic module
- Calibrated X-Y translation stage

Test Pattern: Use the three-line grille patterns in Figure II.11-1 for vertical and horizontal lines each 1-pixel wide. Lines in test pattern are displayed at 100% L_{max} must be positioned along the top, bottom, and side edges of the addressable screen, as well as along both the vertical and horizontal centerlines (major and minor axes).



1-pixel-wide lines displayed at 100% L_{max}

Figure II.11-1 Three-line grille test patterns.

Procedure: Use diode optic module to locate center of line profiles in conjunction with calibrated X-Y translation to measure screen x, y coordinates of lines at the ends of the major and minor axes.

Data: Compute the image width defined as the average length of the horizontal lines along the top, bottom and major axis of the screen. Similarly, compute the image height defined as the average length of the vertical lines along the left side, right side, and minor axis of the screen. Compute the diagonal screen size as the square root of the sum of the squares of the width and height.

Table II.11-1. Image Size

	Monoscopic Mode
Addressability (H x V)	1024 x 1024
H x V Image Size (inches) Diagonal Image Size (inches)	10.996 x 10.918 15.495

II.12. Contrast Modulation

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 5.2, page 57.

Contrast modulation (Cm) for 1-on/1-off grille patterns displayed at 50% Lmax exceeded Cm = 73% in Zone A, and exceeded Cm = 72% in Zone B.

Objective: Quantify contrast modulation as a function of screen position.

Equipment:
- Video generator
- Spatially calibrated CCD or photodiode array optic module
- Photometer with linearized response

Procedure: The maximum video modulation frequency for the 1024 x 1024 format was examined using horizontal and vertical grille test patterns consisting of alternating lines with 1 pixel on, 1 pixel off. Contrast modulation was measured in both horizontal and vertical directions at screen center and at eight peripheral screen positions. The measurements should be along the horizontal and vertical axes and along the diagonal from these axes. Use edge measurements no more than 10% of screen size in from border of active screen. The input signal level was set so that 1-line-on/1-line-off horizontal grille patterns produced a screen area-luminance of 25% of maximum level, Lmax.

Zone A is defined as a 24 degree subtended circle from a viewing distance of 18 inches (7.6 inch circle). Zone B is the remainder of the display. Use edge measurements no more than 10% of screen size in from border of active screen area to define Cm for Zone B (remaining area outside center circle). Determine Cm at eight points on circumference of circle by interpolating between center and display edge measurements to define Cm for Zone A. If measurements exceed the threshold, do not make any more measurements. If one or more measurements fail the threshold, make eight additional measurements at the edge (but wholly within) the defined circle.

Data: Values of vertical and horizontal Cm for Zone A and Zone B are given in Table II.12-1. The contrast modulation, Cm, is reported (the defining equation is given below) for the 1-on/1-off grille patterns. The modulation is equal to or greater than 36% in Zone A, and is equal to or greater than 21% in Zone B.

$$C_m = \frac{L_{peak} - L_{valley}}{L_{peak} + L_{valley}}$$

Table II.12-1. Contrast Modulation
Corrected for lens flare and Zone Interpolation

Zone A = 7.6-inch diameter circle for 24-degree subtended angle at 18-inch viewing distance

	Left				Minor				Right	
	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille
Top	84%	74%			81%	74%			83%	73%
			84%	75%	82%	74%	83%	74%		
Major	88%	76%	86%	76%	84%	76%	87%	76%	88%	76%
			80%	76%	83%	73%	83%	74%		
Bottom	76%	76%			83%	72%			82%	72%

Zone A = 7.82-inch diameter circle for 40% area

	Left				Minor				Right	
	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille
Top	84%	74%			81%	74%			83%	73%
			84%	75%	82%	74%	83%	74%		
Major	88%	76%	87%	76%	84%	76%	87%	76%	88%	76%
			80%	76%	83%	73%	83%	74%		
Bottom	76%	76%			83%	72%			82%	72%

II.13. Pixel Density

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.13, p 9.

Pixel density was 93 H x 94 V pixels per inch (ppi) as tested for the 1024 x 1024-line format.

Objective: Characterize density of image pixels

Equipment: Measuring tape with at least 1/16 inch increments

Procedure: Measure H&V dimension of active image window and divide by vertical and horizontal addressability

Data: Define horizontal and vertical pixel density in terms of pixels per inch

Table II.13-1. Pixel-Density

	Monoscopic Mode
H x V Addressability, Pixels	1024 x 1024
H x V Image Size, Inches H x V Pixel Density, ppi	10.996 x 10.918 93 x 94

II.15. Straightness

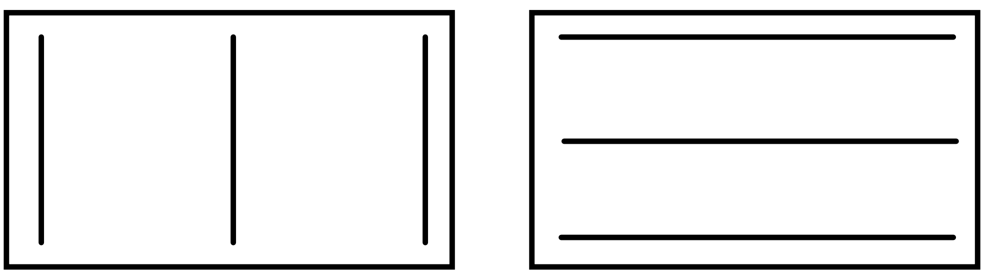
Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 6.1 Waviness, page 67.

Waviness, a measure of straightness, did not exceed 0.27% of the total image height or width.

Objective: Measure beam position on the CRT display to quantify effects of waviness which causes nonlinearities within small areas of the display distorting nominally straight features in images, characters, and symbols.

Equipment:
- Video generator
- Spatially calibrated CCD or photodiode array optic module
- Calibrated X-Y translation stage

Test Pattern: Use the three-line grille patterns in Figure II.15-1 for vertical and horizontal lines each 1-pixel wide. Lines in test pattern are displayed at 100% L_{max} must be positioned along the top, bottom, and side edges of the addressable screen, as well as along both the vertical and horizontal centerlines (major and minor axes).



1-pixel-wide lines displayed at 100% L_{max}

Figure II.15-1 Three-line grille test patterns.

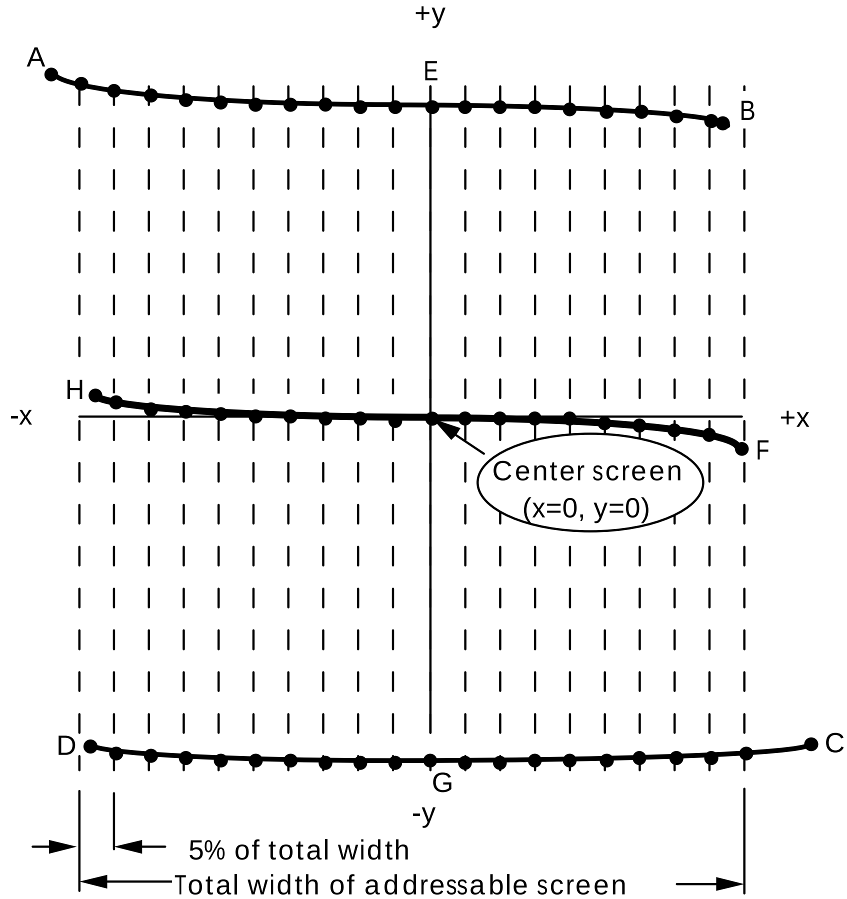


Figure II.15-2 Measurement locations for waviness along horizontal lines. Points A, B, C, D are extreme corner points of addressable screen. Points E, F, G, H are the endpoints of the axes.

Procedure: Use diode optic module to locate center of line profiles in conjunction with calibrated X-Y translation to measure screen x, y coordinates along the length of a nominally straight line. Measure x, y coordinates at 5% addressable screen intervals along the line. Position vertical lines in video to land at each of three (3) horizontal screen locations for determining waviness in the horizontal direction. Similarly, position horizontal lines in video to land at each of three (3) vertical screen locations for determining waviness in the vertical direction.

Data: Tabulate x, y positions at 5% addressable screen increments along nominally straight lines at top and bottom, major and minor axes, and left and right sides of the screen as shown in Table II.15-I. Figure II.15-3 shows the results in graphical form.

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Table II.15-1. Straightness
MegaScan MD2-4810-LS
Tabulated x, y positions at 5% addressable screen increments
along nominally straight lines.

Top		Bottom		Major		Minor		Left Side		Right Side	
x	y	x	y	x	y	x	y	x	y	x	y
-5463	5454	-5329	-5473	-5404	-12	-1	5462	-5463	5454	5608	5466
-4500	5461	-4500	-5471	-4500	-9	-5	4500	-5456	4000	5604	4500
-4000	5462	-4000	-5469	-4000	-7	-7	4000	-5456	4000	5600	4000
-3500	5465	-3500	-5467	-3500	-6	-7	3500	-5450	3500	5596	3500
-3000	5465	-3000	-5464	-3000	-4	-7	3000	-5444	3000	5592	3000
-2500	5464	-2500	-5462	-2500	-3	-7	2500	-5437	2500	5590	2500
-2000	5463	-2000	-5460	-2000	-2	-6	2000	-5429	2000	5587	2000
-1500	5462	-1500	-5458	-1500	-2	-5	1500	-5421	1500	5585	1500
-1000	5462	-1000	-5457	-1000	-1	-3	1000	-5413	1000	5583	1000
-500	5462	-500	-5455	-500	-1	-1	500	-5405	500	5581	500
0	5462	0	-5454	0	0	0	0	-5399	0	5581	0
500	5463	500	-5454	500	0	1	-500	-5394	-500	5581	-500
1000	5464	1000	-5454	1000	0	2	-1000	-5388	-1000	5583	-1000
1500	5466	1500	-5454	1500	0	4	-1500	-5384	-1500	5585	-1500
2000	5467	2000	-5454	2000	-1	6	-2000	-5380	-2000	5589	-2000
2500	5469	2500	-5454	2500	-2	10	-2500	-5374	-2500	5594	-2500
3000	5471	3000	-5453	3000	-4	14	-3000	-5368	-3000	5598	-3000
3500	5472	3500	-5452	3500	-5	18	-3500	-5362	-3500	5603	-3500
4000	5472	4000	-5450	4000	-6	23	-4000	-5355	-4000	5606	-4000
4500	5470	4500	-5448	4500	-8	28	-4500	-5348	-4500	5608	-4500
5608	5466	5604	-5443	5579	-16	37	-5455	-5329	-5473	5605	-5443

MegaScan MD2-4810-LS **Tektronix GMA203**

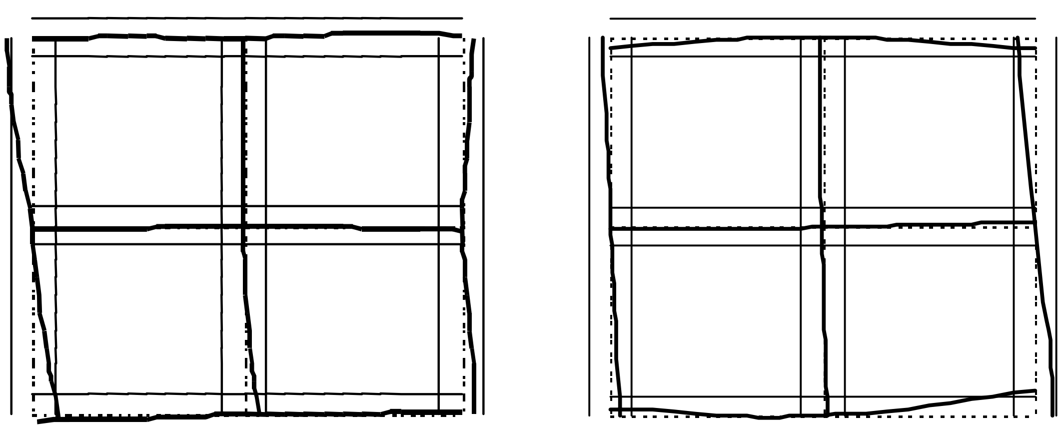

Figure II.15-3 Waviness of MegaScan MD2-4810 LS Monochrome monitor in 1024 x 1024 mode, and Tektronix GMA203 monitor. Departures from straight lines are exaggerated on a 10X scale. Error bars are +/- 0.5% of total screen size.

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II.16. Refresh Rate

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.16, p 9.

Vertical refresh rate for the 1024 x 1024 stereo format was set to 120 Hz (60 Hz per eye).

Objective: Define vertical and horizontal refresh rates.

Equipment: Programmable video signal generator.

Procedure: The refresh rates were programmed into the Quantum Data 8701 test pattern generator for 72 Hz minimum for monoscopic mode and 120 Hz minimum for stereoscopic mode, where possible.

Data: Report refresh rates in Hz.

Table II.16-1 Refresh Rates as Tested

	Stereo Mode
Addressability	1024 x 1024
Vertical Scan	120 Hz
Horizontal Scan	126.72 kHz

II.17. Extinction Ratio

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.17, p10.

Stereo extinction ratio averaged 29.6:1 (37.1 left, 22.1 right) at screen center. Luminance of white varied by up to 11.1 % across the screen. Chromaticity variations of white were less than 0.005 delta u'v' units.

Objective: Measure stereo extinction ratio

Equipment: Two “stereo” pairs with full addressability. One pair has left center at command level of 255 (or Cmax) and right center at 0. The other pair has right center at command level of 255 (or Cmax) and left center at 0.

Stereoscopic-mode measurements were made using a commercially-available ZScreen with passive polarized eyeglasses.

Procedure: Calibrate monitor to 0.1 fL Lmin and 35 fL Lmax (no ambient). Measure ratio of Lmax to Lmin on both left and right side images through the stereo system.

Data: Extinction ratio (left) = L (left,on, white/black)/left,off, black/white)

L(left,on, white/black) ~ trans(left,on)*trans(stereo)*L(max)*Duty(left)
+ trans(left,off)*trans (stereo)*L(min)*Duty (right)
Use left,off/right,on to perform this measurement

Extinction ratio (right) = L (right,on,white/black)/right,off, black/white)

L(right,on, white/black) ~
trans(right,on)*trans(stereo)*L(max)*Duty(right)
+ trans(right,off)*trans (stereo)*L(min)*Duty (left)
Use left,on/right,off to perform this measurement

Stereo extinction ratio is average of left and right ratios defined above.

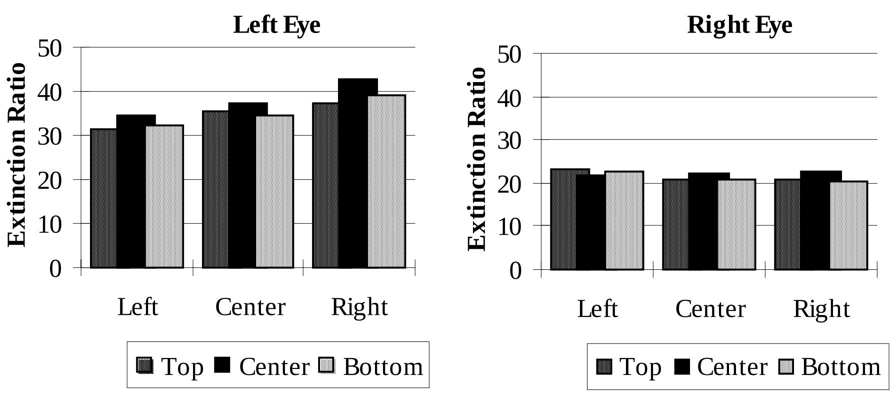


Fig.II.17-1. Spatial Uniformity of extinction ratio in stereo mode.

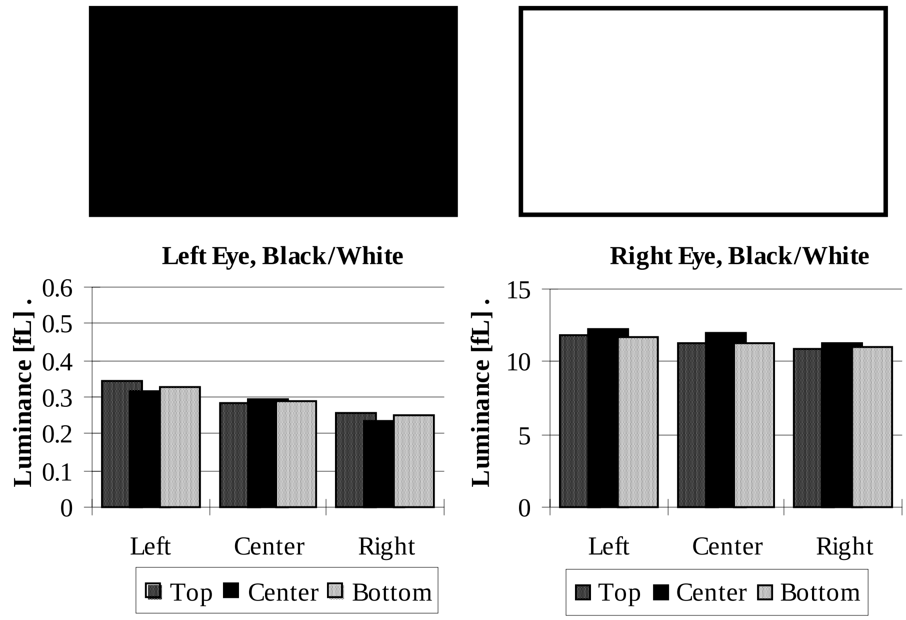


Fig.II.17-2. Spatial Uniformity of luminance in stereo mode when displaying black to the left eye while displaying white to the right eye.

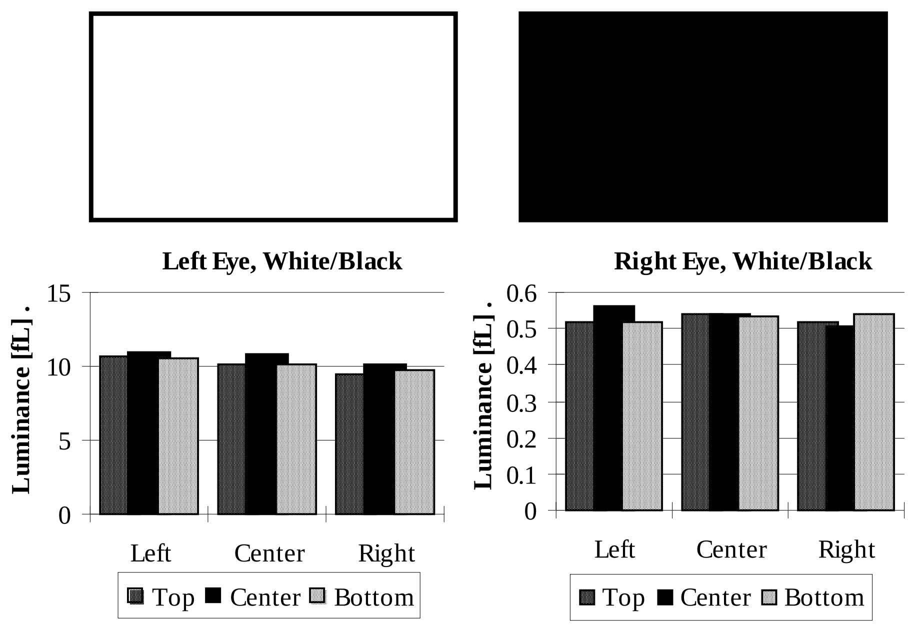


Fig.II.17-3. Spatial Uniformity of luminance in stereo mode when displaying white to the left eye while displaying black to the right eye.

II.18. Linearity

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 6.2, page 73.

The maximum nonlinearity of the scan was 0.62 % of full screen.

Objective: Measure the relation between the actual position of a pixel on the screen and the commanded position to quantify effects of raster nonlinearity. Nonlinearity of scan degrades the preservation of scale in images across the display.

Equipment:
- Video generator
- Spatially calibrated CCD or photodiode array optic module
- Calibrated X-Y translation stage

Test Pattern: Use grille patterns of single-pixel horizontal lines and single-pixel vertical lines displayed at 100% L_{max}. Lines are equally spaced in addressable pixels. Spacing must be constant and equal to approximately 5% screen width and height to the nearest addressable pixel as shown in Figure II.18-1.

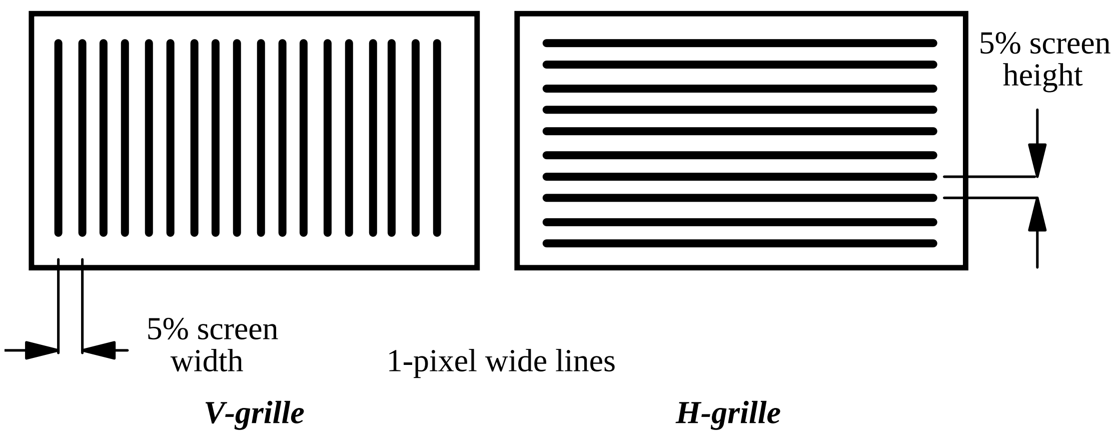


Figure II.18-1. *Grille patterns for measuring linearity*

Procedure: The linearity of the raster scan is determined by measuring the positions of lines on the screen. Vertical lines are measured for the horizontal scan, and horizontal lines for the vertical scan. Lines are commanded to 100% Lmax and are equally spaced in the time domain by pixel indexing on the video test pattern. Use optic module to locate center of line profiles in conjunction with x, y-translation stage to measure screen x, y coordinates of points where video pattern vertical lines intersect horizontal centerline of screen and where horizontal lines intersect vertical centerline of the CRT screen as shown in Figure II.18-2.

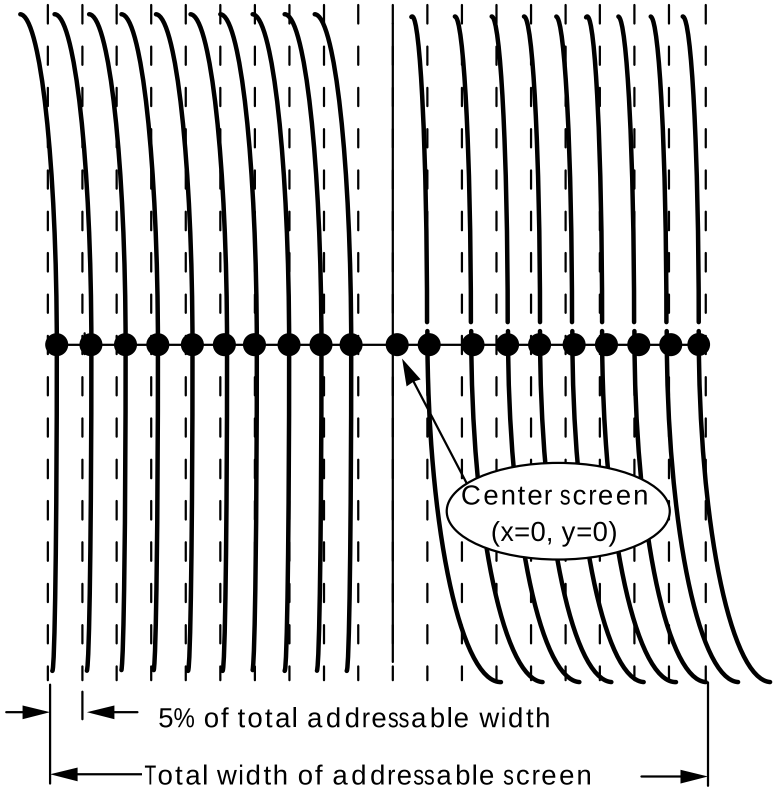


Figure II.18-2. *Measurement locations for horizontal linearity along the major axis of the display. Equal pixel spacings between vertical lines in the grille pattern are indicated by the dotted lines. The number of pixels per space is nominally equivalent to 5% of the addressable screen size.*

Data: Tabulate x, y positions of equally spaced lines (nominally 5% addressable screen apart) along major (horizontal centerline) and minor (vertical centerline) axes of the raster. If both scans were truly linear, the differences in the positions of adjacent lines would be a constant. The departures of these differences from constancy impacts the absolute position of each pixel on the screen and is, then, the nonlinearity. The degree of nonlinearity may be different between left and right and between top and bottom. The maximum horizontal and vertical nonlinearities (referred to full screen size) are listed in table II.18-1. The complete measured data are listed in table II.18-2 and shown graphically in Figure II.18-3.

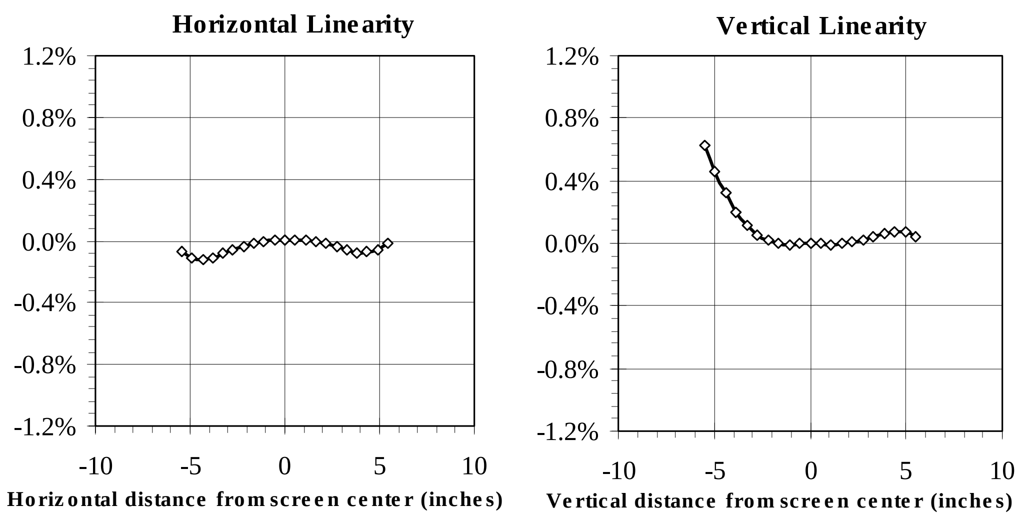
Table II.18-1. Maximum Horizontal and Vertical Nonlinearities between equal spacings

Monitor	Left Side	Right Side	Top	Bottom
MegaScan MD2-4810-LS	-0.12%	-0.08%	0.07%	0.62%
Tektronix GMA203	-1.06%	-0.40%	0.40%	0.03%

Table II.18-2. Horizontal and Vertical Nonlinearities Data
MegaScan MD2-4810-LS

Vertical Lines x-Position (mils)		**Horizontal lines y-Position (mils)**	
Left Side	Right Side	Top	Bottom
-5447	5438	5510	-5437
-4908	4890	4962	-4904
-4365	4344	4412	-4369
-3820	3799	3860	-3832
-3273	3258	3308	-3291
-2726	2716	2755	-2747
-2180	2174	2203	-2200
-1634	1631	1651	-1652
-1089	1088	1100	-1102
-544	544	550	-551
0	0	0	0

MegaScan MD2-4810-LS



Tektronix GMA203

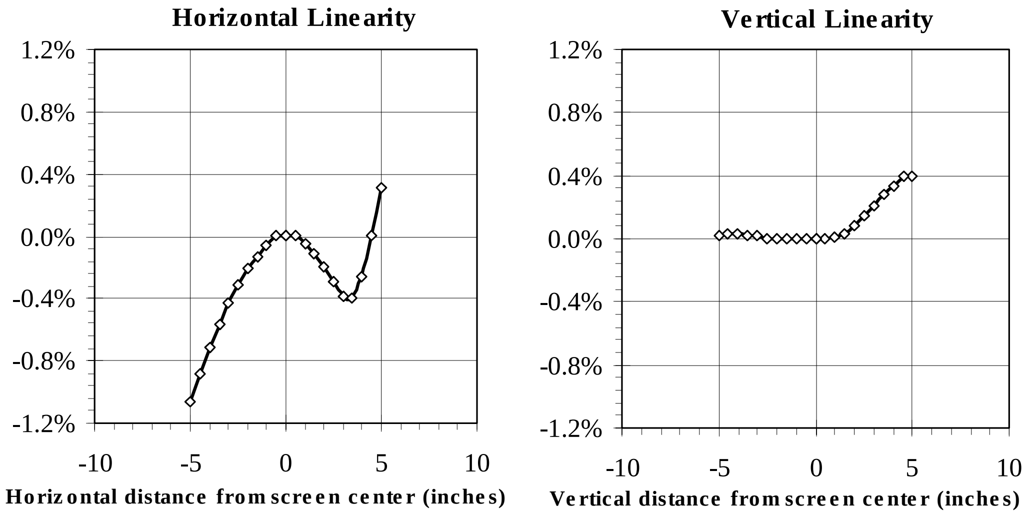


Fig. II.18-5 Horizontal and vertical linearity characteristics.

II.19. Jitter/Swim/Drift

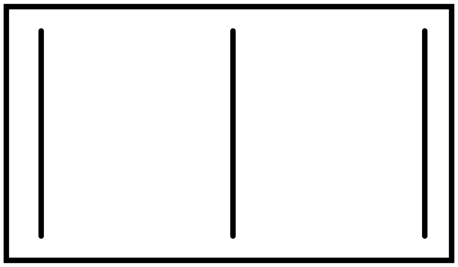
Reference: Monochrome CRT Monitor Performance, Draft Version 2.0 Section 6.4, p80.

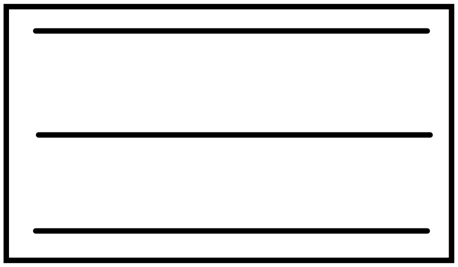
Maximum jitter, swim, and drift were 3.93 mils, 4.36 mils and 4.89 mils, respectively.

Objective: Measure amplitude and frequency of variations in beam spot position of the CRT display. Quantify the effects of perceptible time varying raster distortions: jitter, swim, and drift. The perceptibility of changes in the position of an image depend upon the amplitude and frequency of the motions which can be caused by imprecise control electronics or external magnetic fields.

Equipment:
- Video generator
- Spatially calibrated CCD or photodiode array optic module
- Calibrated X-Y translation stage

Test Pattern: Use the three-line grille patterns in Figure II.19-1 for vertical and horizontal lines each 1-pixel wide. Lines in test pattern must be positioned along the top, bottom, and side edges of the addressable screen, as well as along both the vertical and horizontal centerlines (major and minor axes).





V-grille for measuring horizontal motion H-grille for measuring vertical motion

1-pixel wide lines

Three-line grille test patterns.
Figure II.19-1

Procedure: With the monitor set up for intended scanning rates, measure vertical and horizontal line jitter (0.01 to 2 seconds), swim (2 to 60 seconds) and drift (over 60 seconds) over a 2.5 minute duration as displayed using grille video test patterns. Generate a histogram of raster variance with time. The measurement interval must be equal to a single field period.

Optionally, for multi-sync monitors measure jitter over the specified range of scanning rates. Some monitors running vertical scan rates other than AC line frequency may exhibit increased jitter.

Measure and report instrumentation motion by viewing Ronchi ruling or illuminated razor edge mounted to the top of the display. It may be necessary to mount both the optics and the monitor on a vibration damped surface to reduce vibrations.

Data: Tabulate motion as a function of time in x-direction at top-left corner screen location. Repeat for variance in y-direction. Tabulate maximum motions (in mils) with display input count level corresponding to L_{max} for jitter (0.01 to 2 seconds), swim (2 to 60 seconds) and drift (over 60 seconds) over a 2.5 minute duration. The data are presented in Table II.19-1. Both the monitor and the Microvision equipment sit on a vibration-damped aluminum-slab measurement bench. The motion of the test bench was a factor of 10 times smaller than the CRT raster motion.

Table II.19-1. Jitter/Swim/Drift
Maximum motions in mils.
Time scales: Jitter 2 sec., Swim 10 sec., and Drift 60 sec.
Signal Generator: Quantum Data FOX 8701

Screen Position		H-lines	V-lines
Center			
	Jitter	0.83	3.93
	Swim	0.74	4.36
	Drift	0.35	4.26
10D corner			
	Jitter	0.96	3.66
	Swim	1.09	3.82
	Drift	1.06	4.89

II.20 Warm-up Period

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.20, p. 10.

A 24-minute warm-up was necessary for luminance stability of Lmin = 0.1 fL +/- 10%.

Objective: Define warm-up period

Equipment: Photometer, test target (full screen 0 count)

Procedure: Turn monitor off for three-hour period. Turn monitor on and measure center of screen luminance (Lmin as defined in Dynamic range measurement) at 1-minute intervals for first five minutes and five minute intervals thereafter. Discontinue when three successive measurements are ± 10% of Lmin.

Data: Pass if Lmin within ± 50% in 30 minutes and ±10% in 60 minutes.

The luminance of the screen (commanded to the minimum input level, 0 for Lmin) was monitored for 120 minutes after a cold start. Measurements were taken every minute. Figure II.20-1 shows the data for 1600 x 1200 format in graphical form. The luminance remains very stable after 60 minutes.

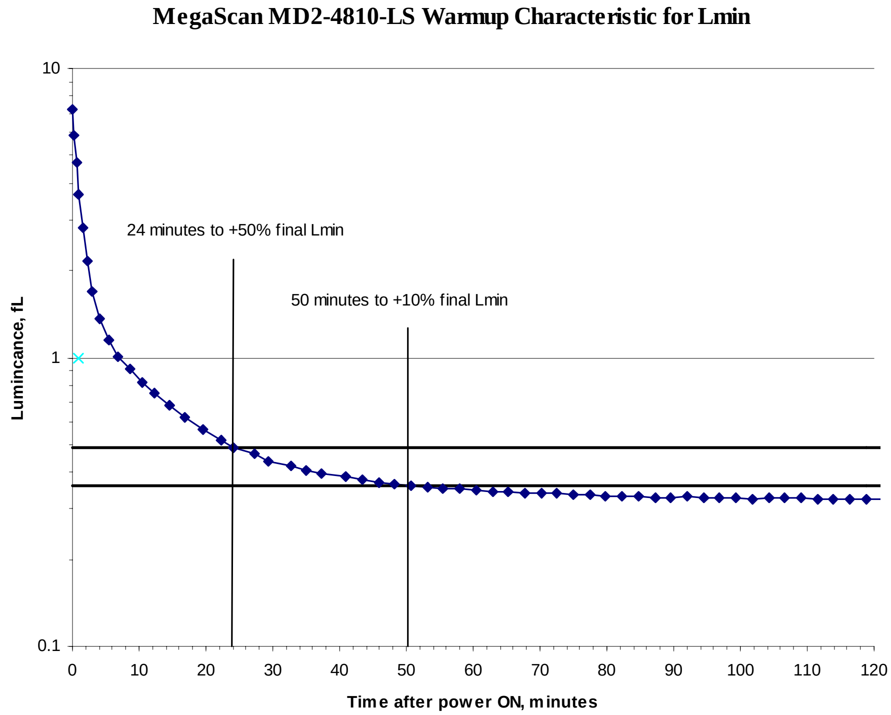


Figure II.20.1. Luminance (fL) as a function of time (in minutes) from a cold start with an input count of 0. (Note suppressed zero on luminance scale).

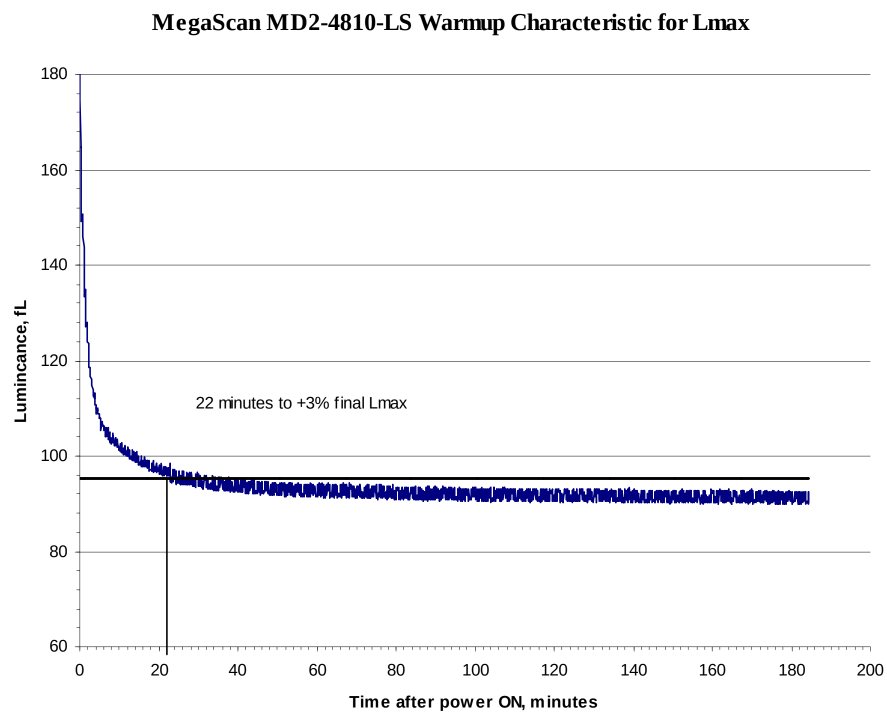


Figure II.20.2. Luminance (fL) as a function of time (in minutes) from a cold start with an input count of 255. (Note suppressed zero on luminance scale). The CRT manufacturer specified maximum luminance "slump" is 3%.

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II. 21 Linewidth at 49 fL

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0 Section 5.1, page 47.

Linewidths (full width half maximum) were measured at screen center. They are 10.7 mils Horizontal x 6.74 mils Vertical at 50% Lmax (49 fL).

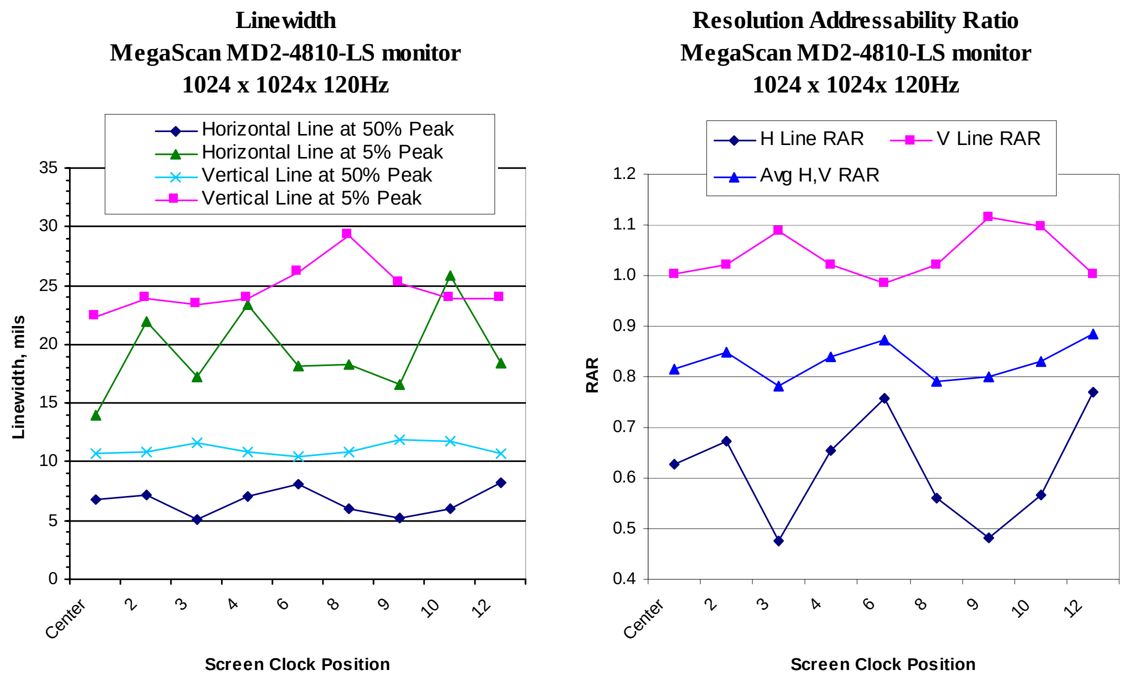

Figure II.21-1. Linewidth (mils) and RAR (Resolution Addressability Ratio) as a function of position on the screen.

Table II.21-1. Linewidths and RAR at 49 fL (50% Lmax)

<u>MegaScan MD2-4810-LS</u>
1024 x 1024 x 120 Hz

Screen Position	VERTICAL Widths of Horizontal Lines			HORIZONTAL Widths of Vertical Line			Resolution Addressability Ratio RAR		
	50%	10%	5%	50%	10%	5%	H Line	V Line	Avg H,V
Center	6.74	12.2	14	10.7	19.6	22.3	0.6	1.0	0.8
2	7.24	16.5	21.9	10.9	19.2	23.9	0.7	1.0	0.8
3	5.12	12	17.2	11.6	20.3	23.4	0.5	1.1	0.8
4	7.02	17.8	23.4	10.9	20.7	23.9	0.7	1.0	0.8
6	8.15	14.2	18.1	10.5	19.7	26.1	0.8	1.0	0.9
8	6.03	12.4	18.3	10.9	19.4	29.2	0.6	1.0	0.8
9	5.17	11.8	16.6	11.9	20.3	25.2	0.5	1.1	0.8
10	6.07	16.5	25.9	11.7	20.2	23.9	0.6	1.1	0.8
12	8.25	15.1	18.4	10.7	18.1	23.9	0.8	1.0	0.9

II. 22 Spot Size at 97 fL

Reference: NIDL Test Procedures for Evaluation of CRT Display Monitors, Version 3.1, 6/15/92, Section 4.4.

Spot size (FWHM) is 12.6 H mils x 8.8 V mils at screen center. Spot shapes exhibit astigmatism along the sides of the screen and vary in vertical size by as much as 104% across the screen.

Spot Size
1024 x 1024 x 120Hz, 97fL

MegScan MD2-4810-LS **Tektronix GMA203**

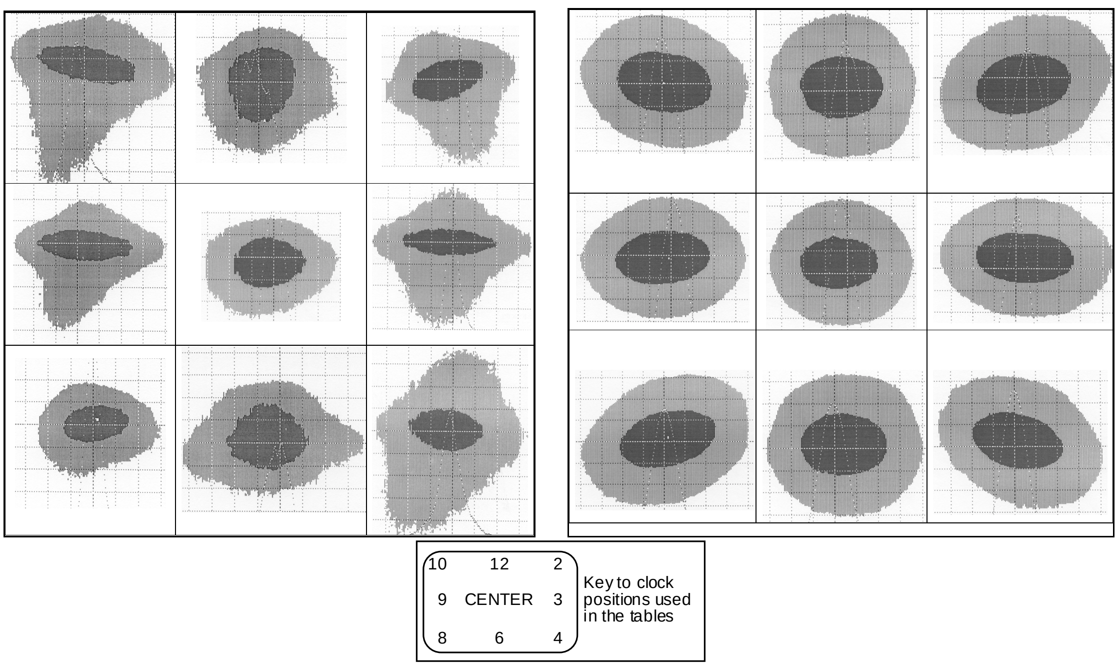

Figure II.22-1. Spot contour plots of MegaScan MD2-4810-LS and Tektronix GMA203 monitors as a function of position on the screen. The outer contour is the 5% intensity level of the spot. The inner contour is the FWHM or 50% intensity level. Screen positions are represented by the position of the spot picture in the figure. The grid pitch is 4 mils. For the measurements, a camera with CCD element size as projected on the CRT screen is 0.21 mils.

Table II.22-1. Spot Size at 97 fL

Horizontal and vertical spot size (in mils) at 9 screen positions. Size determined at the 50% (FWHM) and 5% intensity levels of the spot contours plotted in Figure II.22-1. Screen luminance is 97 fL. Timing format is 1024 x 1024 x 120 Hz.

	MegaScan MD2-4810-LS				Tektronix GMA203			
Position	50% H	50% V	5% H	5% V	50% H	50% V	5% H	5% V
Ctr	12.6	8.8	23.6	17.6	14.2	9.1	25.6	22.4
2	12.6	7.4	23.2	23.7	17.8	11.4	32.5	25.1
3	16.7	4.9	28.5	24.1	18.3	8.7	32.0	21.5
4	13.0	7.4	25.7	32.5	16.9	10.1	30.6	24.2
6	13.9	11.6	31.4	19.5	15.5	11.0	28.3	25.6
8	11.6	6.5	20.8	16.7	18.3	10.5	32.0	24.2
9	17.1	5.6	26.9	23.7	17.4	9.6	30.6	21.9
10	17.1	8.8	28.9	30.1	16.9	10.5	30.6	23.3
12	11.4	13.4	23.6	23.2	15.1	11.0	27.0	25.6
Average	14.0	8.3	25.9	23.4	16.7	10.2	29.9	23.8
Min	11.4	4.9	20.8	16.7	14.2	8.7	25.6	21.5
Max	17.1	13.4	31.4	32.5	18.3	11.4	32.5	25.6
Range	41%	104%	41%	67%	25%	27%	23%	17%

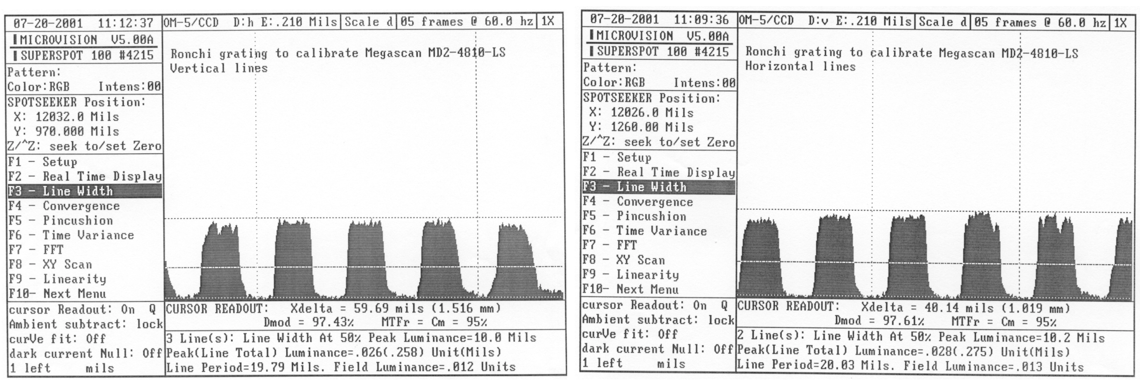

Figure II.22-2. Luminance profiles of a 20-mil pitch Ronchi ruling (10-mil wide lines spaced 10 mils apart) showing better than 2% spatial calibration of OM-5 CCD optic module used for spot measurements.

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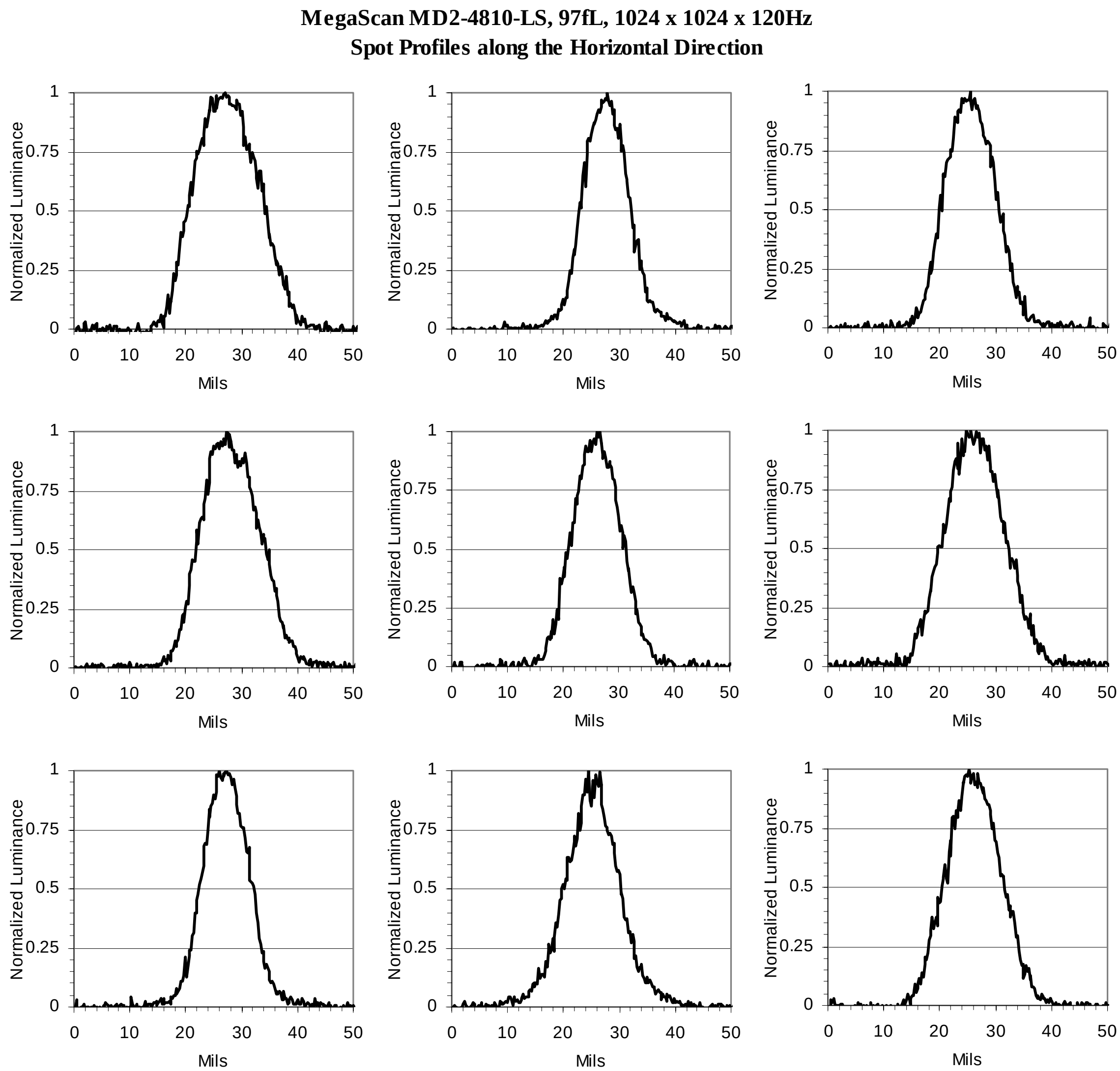

Figure II.22-3. Luminance profiles along the horizontal direction of spots of the MegaScan MD2-4810-LS monitor as a function of position on the screen. Screen positions are represented by the position of the spot picture in the figure.

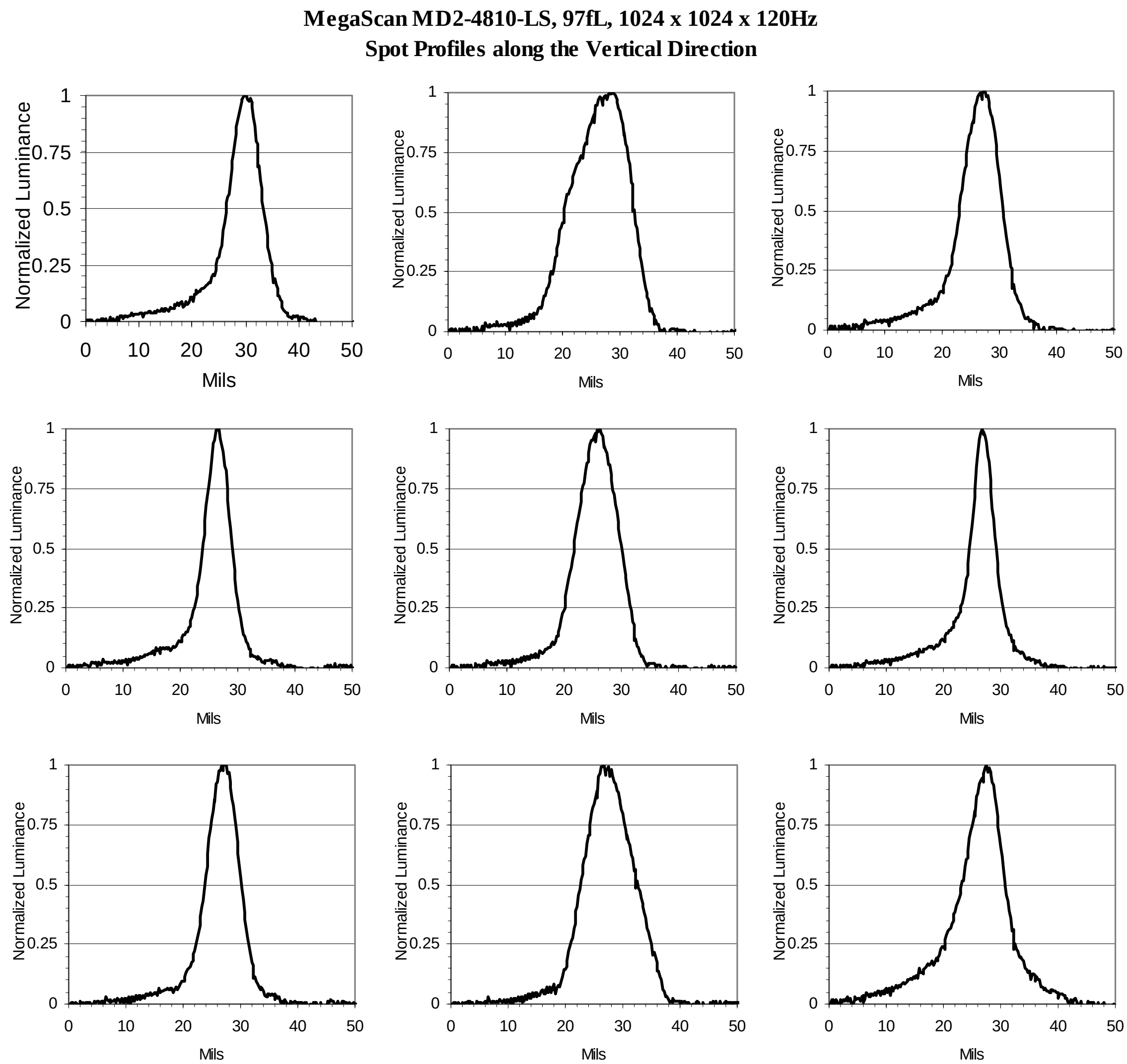

Figure II.22-4. Luminance profiles along the vertical direction of spots of the MegaScan MD2-4810-LS monitor as a function of position on the screen. Screen positions are represented by the position of the spot picture in the figure.

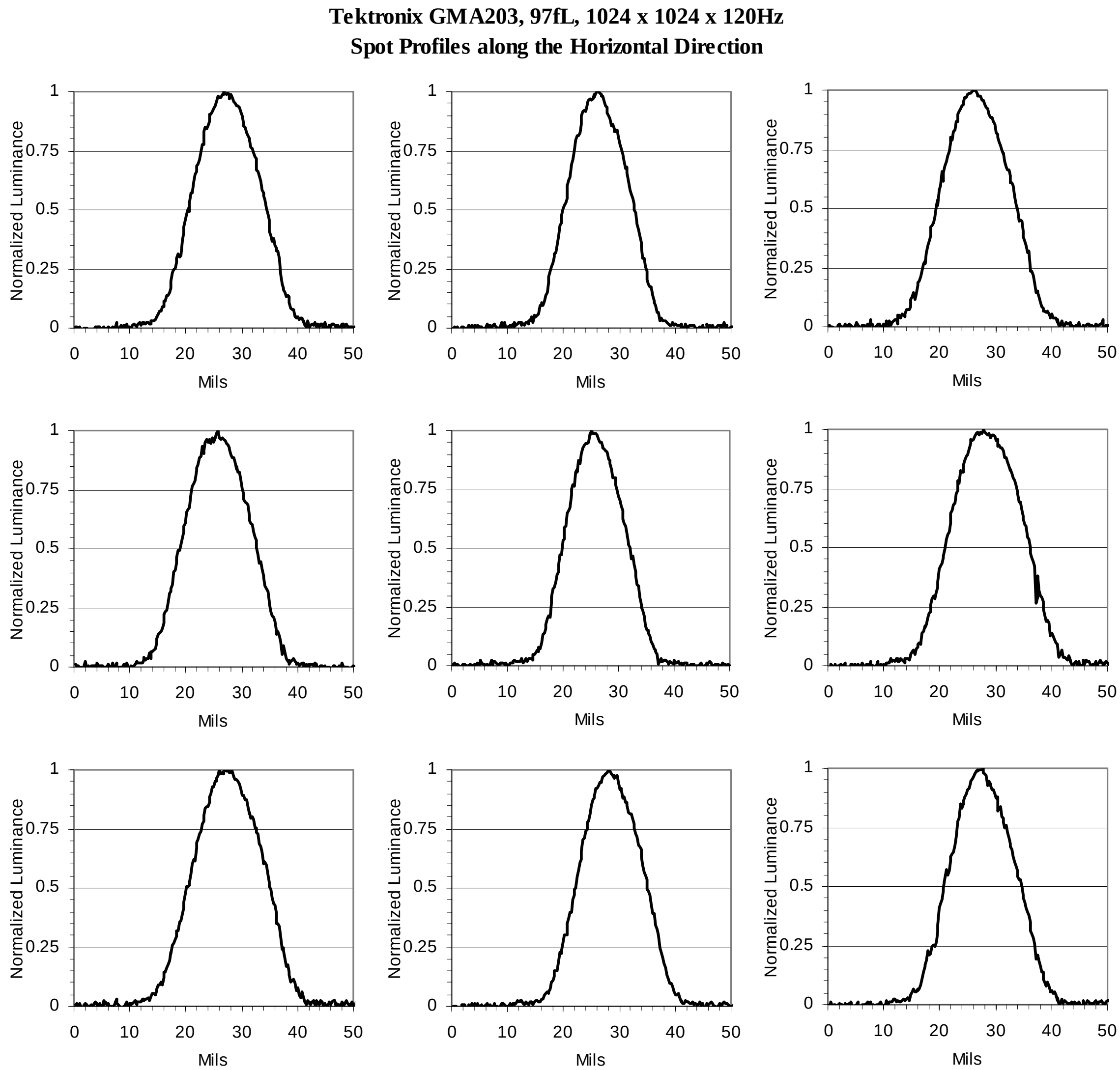

Figure II.22-5. Luminance profiles along the horizontal direction of spots of the Tektronix GMA203 monitor as a function of position on the screen. Screen positions are represented by the position of the spot picture in the figure.

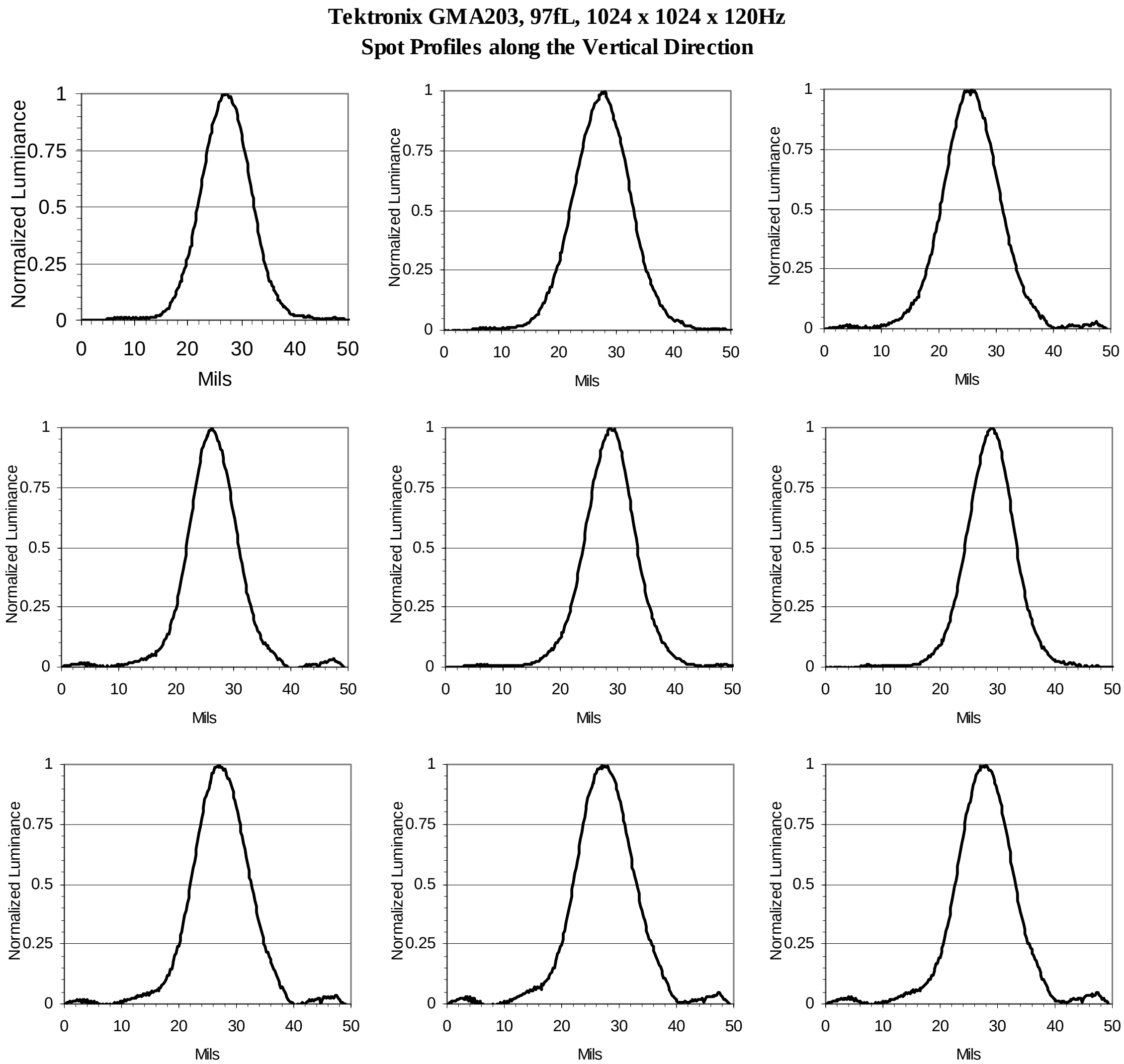

Figure II.22-6. Luminance profiles along the vertical direction of spots of Tektronix GMA203 monitor as a function of position on the screen. Screen positions are represented by the position of the spot picture in the figure.

II. 23 Briggs Scores at 97 fL

Reference: SofTrak User's Guidelines and Reference Manual version 3.0, NIDL, Sept. 1994, page 3.

Briggs Scores for the BTP #4 Delta-1, Delta-3, Delta-7 and Delta-15 contrast ratio target sets for 1024 x 1024 x120 Hz at 97 fL averaged 21, 51, 71, and 81, respectively. These scores are slightly better than Briggs scores for the Tektronix GMA203 monitor (15, 51, 65, and 83).

The Briggs series of test targets were developed to visually evaluate the image quality of grayscale monitors. Three observers selected the maximum scores for each target set displayed on both the MegaScan MD2-4810-LS and Tektronix GMA203 monitors. The operating and environmental conditions were identical to ensure a level-playing-field comparison between the two monitors. Magnifying devices were used when deemed by the observer to be advantageous in achieving higher scores.

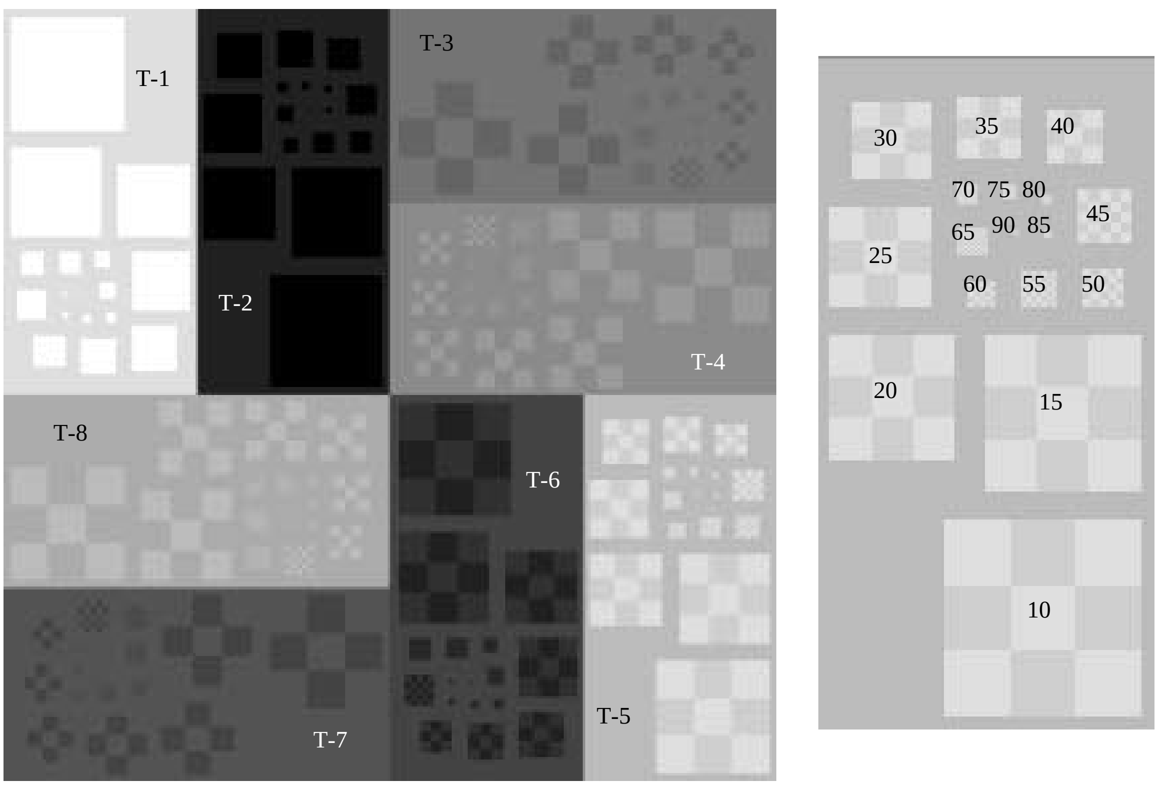

Figure II.23.1. Briggs BPT#4 Test Patterns comprised of 8 targets labeled T-1 through T-8. A series of 17 checkerboards are contained within each of the 8 targets. Each checkerboard is assigned a score value ranging from 10 to 90. Higher scores are assigned to smaller checkerboards.

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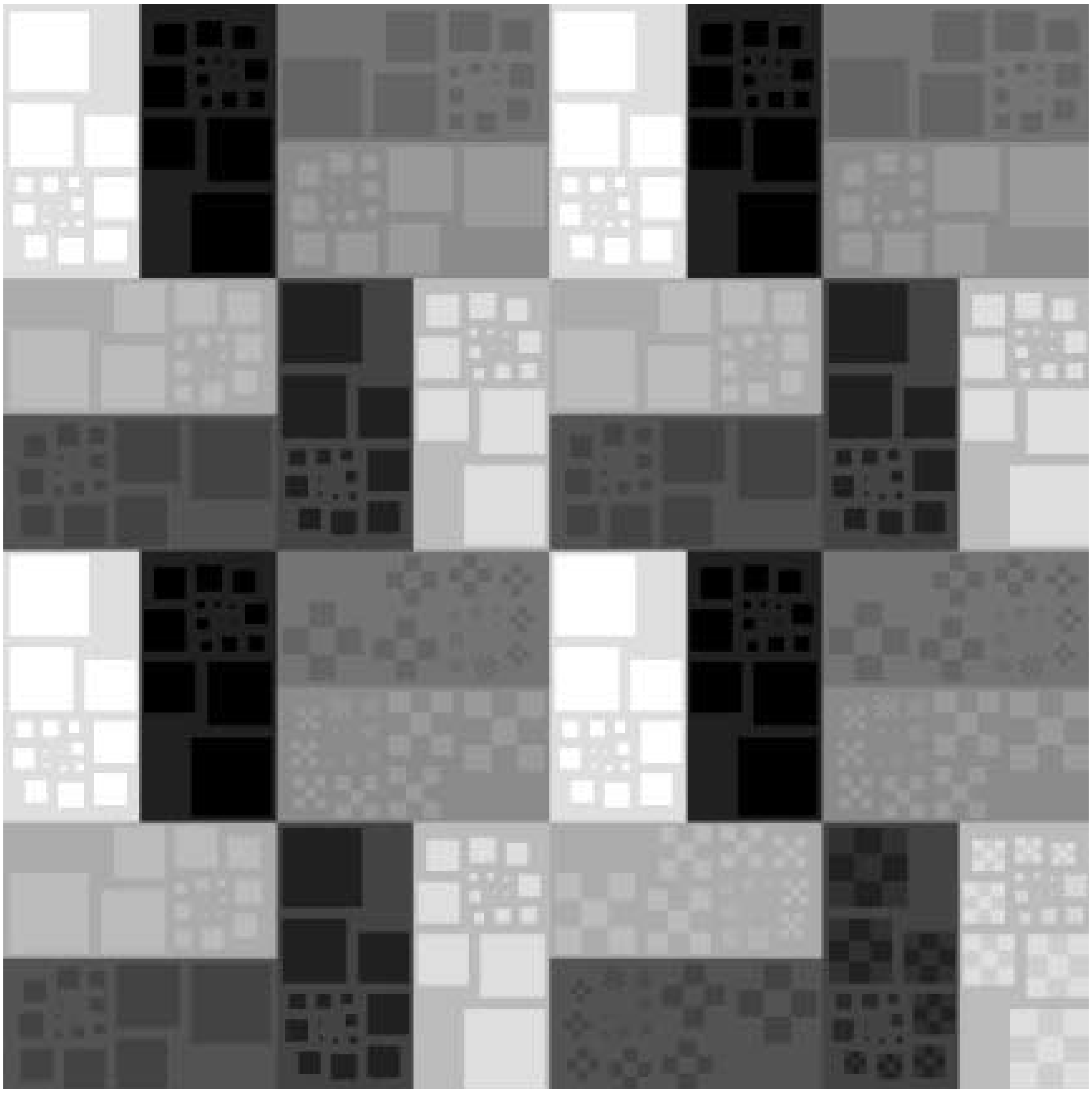

Figure II.23.2. 1024 x 1024 mosaic comprised of four 512 x 512 Briggs BPT#4 Test Patterns. The upper left quadrant contains the set of 8 Briggs targets with command contrast of delta 1. The upper right quadrant contains command contrast of delta. Delta 7 targets are in the lower left quadrant and delta 15 targets are in the lower right.

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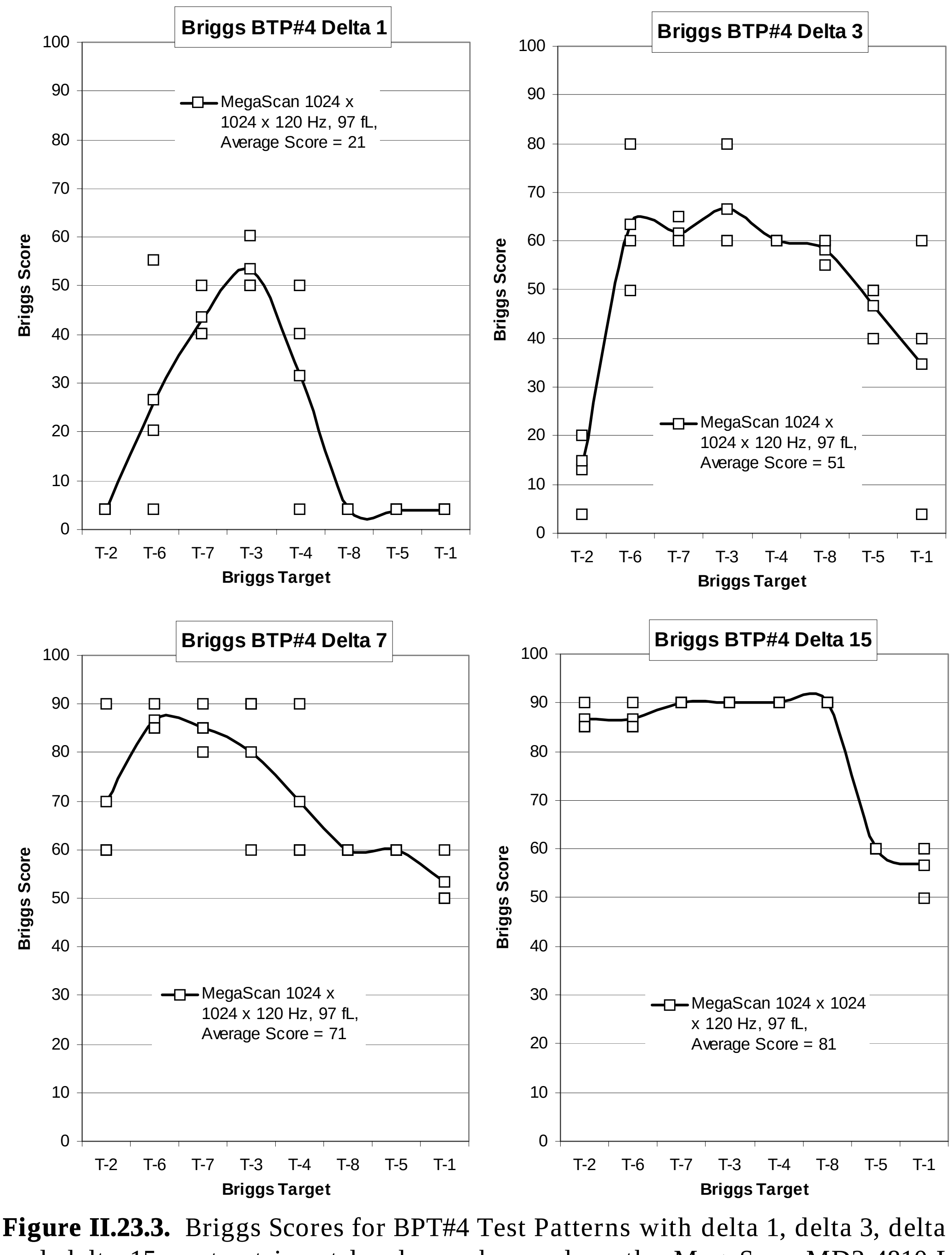

Figure II.23.3. Briggs Scores for BPT#4 Test Patterns with delta 1, delta 3, delta 7 and delta 15 contrast input levels as observed on the MegaScan MD2-4810-LS monitor operating at 1024 x 1024 x 120Hz and 97fL Lmax, 0.27fL Lmin.

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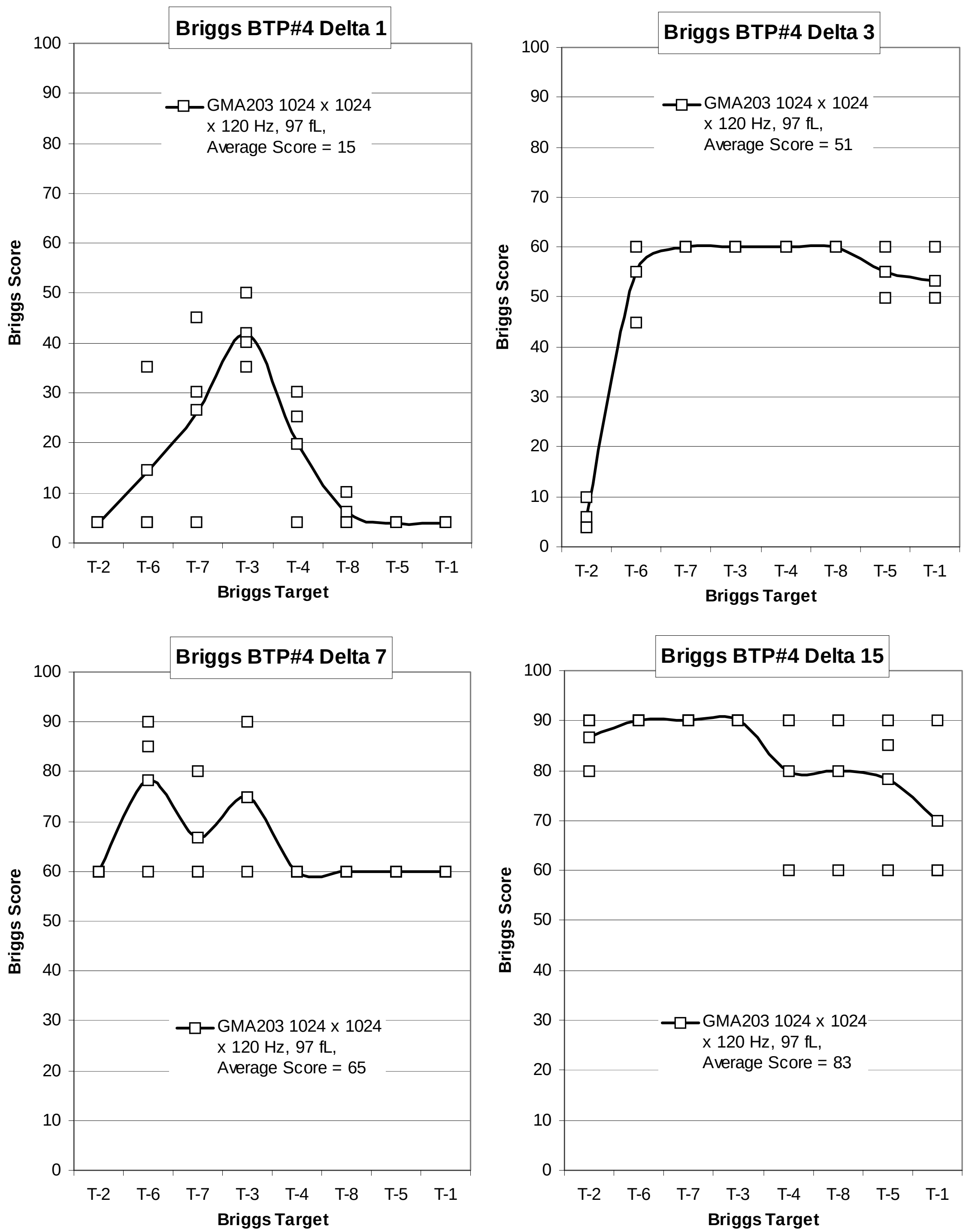

Figure II.23.4. Briggs Scores for BPT#4 Test Patterns with delta 1, delta 3, delta 7 and delta 15 contrast input levels as observed on the Tektronix monitor operating at 1024 x 1024 x 120Hz and 97fL Lmax, 0.27fL Lmin.